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THE
LARYNGOSCOPE.

VOL. LVI MAY, 1946. No. 5

CORRELATIONS BETWEEN BONE AND AIR CONDUCTION ACUITY MEASUREMENTS OVER WIDE FREQUENCY RANGES IN DIFFERENT TYPES OF HEARING IMPAIRMENTS.*

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Iowa City, Iowa.

This paper presents an analysis of the results of threshold measurements from 128 to 8,192 cycles of both the bone and air conduction acuity of patients with various types of ear lesions. Numerous articles of similar nature have appeared in the literature during the past few years, some of which, however, contain uncertain and contradictory conclusions. As long as significant differences of opinion exist in regard to the efficacy of different test methods and the interpretation of results, further work along these lines seems pardonable if not necessary. This study attempts to present a description of the instruments, techniques, experimental controls and results in such a manner that the contents will not add to the general confusion but will be instrumental in clarifying certain test procedures, objectives and interpretations of the functional examination of hearing.

The following aspects of bone conduction acuity measurements are discussed in the present paper:

I. Difficulties involved in tuning fork measurements.

II. The "air-conduction bone-conduction differential" of audiometer vibrators.

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III. Results of audiometric measurements.

IV. Masking of bone conducted sound.

V. The Weber, Schwabach and Rinne tests with the bone conduction vibrator.

VI. The Gellé, Bing and occlusion tests with the vibrator.

VII. Increased bone conduction acuity.

VIII. Disproportionately decreased bone conduction acuity.

IX. Threshold of vibration by bone conduction.

X. Reliability of audiometer bone conduction vibrators.

XI. Interpretation of the relationships between air and bone conduction acuity threshold measurements.

DIFFICULTIES INVOLVED IN TUNING FORK MEASUREMENTS.

At the present time the most popular and universally used instrument for the clinical testing of hearing, particularly bone conduction acuity, is the tuning fork. Past experience has demonstrated that an examiner with a set of forks with which he is familar can form a clinically useful estimate of the degree and type of hearing impairment of a patient after more or less experience correlating test results with those obtained on the normal ear, plus the information derived from the history and physical examination. Such observations and measurements, fortified by his own clinical experience, are significant and of indispensable value to the individual otologist; however, the results and conclusions from tests with forks by this examiner would be of limited value to others unless all possessed calibrated sets of forks and employed similar techniques and methods of recording their findings to enable quantitative comparisons between them.

In spite of the fact that tuning forks have been used so generally during the past several decades, unfortunately identical or standardized sets of forks, testing techniques and uniform methods of recording data, up to the present time, have not been as universally adopted. It has long been realized that such uniformity or standardization is advisable from both the clinical and research points of view.

The usual bone and air conduction fork tests, as commonly

performed, supply sufficient data to enable the examiner to determine grossly at best if the bone conduction acuity is nearer normal than the air conduction or if both are reduced. This is particularly true of the technique in which the air conduction acuity with forks is obtained in terms of "distance heard" and the bone conduction as "seconds diminished or increased." For example, assume a 256 cycle fork which, when struck a given blow, is heard by the normal ear a distance of 12 inches. If a patient hears this same fork a distance of three inches and the Schwabach with the same fork indicates that his bone conduction acuity is decreased three seconds, does his air conduction loss exceed the bone conduction loss or is the loss equal for both air and bone conduction? The difficulties involved in comparing "inches loss" for air conduction with "seconds loss" by bone conduction are apparent at once. An accurate comparison can be made only by reducing each type of measurement to a common denominator of some sort. Unfortunately, a determination of the number of seconds a given fork, whether standardized or not, is heard by both air and bone conduction does not enable a direct accurate quantitative comparison between the air and bone conduction acuity. This is due to the fact that a given number of seconds loss by air conduction is not equal or equivalent to the same number of seconds loss by bone conduction since practically all forks dissipate their energy more rapidly when held against the skull to obtain bone conduction measurements than when held in the hand near the external auditory meatus for air conduction measurements. Accurate quantitative comparisons between air and bone conduction acuity, when the measurements are made with forks and recorded in terms of "seconds heard," can be made only by converting the "seconds heard" by air and by bone conduction into equivalent values or units of measurement which themselves are directly comparable to each other. Fowler[6] has suggested an "alternate placement technique" by means of which comparable measurements can be obtained with a given fork for both air and bone conduction acuity, which will be described later.

Fletcher[5] recognized the difficulties involved in making comparable acuity measurements with different testing instru-

ments and techniques for both air and bone conduction when he pointed out: "It is highly desirable that a single scale be used for representing the degree of hearing which is independent of the method used and which has a general application. . . ." The method of measurement which Fletcher suggested involves the use of the decibel. Within the past two decades the decibel has come into practically universal use in telephony, radio, sound moving pictures, phonograph record recording, architectural acoustics, public address, noise reduction, and all other fields and research activities in which measurements of sound intensity are desirable. The attenuation dials (volume controls)of practically all the audiometers now available also are calibrated in decibels. It is obvious that if tuning fork measurements in terms of "seconds heard" for both air conduction and bone conduction could be reduced to decibels, then "seconds heard" by both air and bone conduction would have a common denominator and could be compared directly with each other.

The technique for expressing "seconds heard" in terms of decibels with forks for air conduction measurements, when the damping constants of the forks are known, has been described repeatedly in the literature since about 1920. The damping constant or decrement of a tuning fork may be defined as the decrease in sound intensity in decibels per second emitted by the fork. The decrements of forks commonly used by otologists vary roughly from 0.5 to 3 db. per second when held in the hand. To obtain the hearing loss in decibels for a given fork, the decrement of which is known, the difference in the number of seconds that the normal ear and the patient hears the fork is multiplied by the decrement. For example, assume a fork with a decrement of 1.2 db. per second, which, when struck a "constant" blow, is heard 40 seconds by the normal ear. If a hard-of-hearing patient hears this fork for only 11 seconds, the difference in the time heard by the normal and the hard-of-hearing patient is multiplied by 1.2 to give the hearing loss in decibels, which in this case is 34.8 db. ($40 - 11 = 29 \times 1.2 = 34.8$). It is possible by means of a variation in technique to eliminate the necessity of the constant blow if the examiner's hearing is normal or the proper

correction factor applied if he has abnormal hearing. In this latter method the number of seconds that the examiner can hear the fork after the patient stops hearing it in a noise-free environment is multiplied by the decrement to obtain the patient's hearing loss in decibels.

It is generally known that tuning forks "die down" more rapidly—have greater damping constants—when held in contact with the head than when held in the hand near the ear; however, up to the present time little has been written about the use of forks for indicating bone conduction acuity in decibels. This undoubtedly is due in part to the fact that the determination of the decrement of a fork when held against the head presents a difficult problem in physical measurement. Since a search of the literature disclosed no quantitative data relative to the magnitude of the difference of the decrements of forks when used for air and bone conduction acuity measurements, it was necessary to devise a method for calculating the decrements of forks under the different conditions imposed by the air and bone conduction tests. Merely a brief description of the methods used will be given in the present paper.

In order to obtain the decrements of the forks for the air conduction measurements the forks were held in the hand a given distance from the microphone connected to an amplifier, into the output of which was plugged a power output lever meter or indicator, calibrated in decibels. The time (in seconds) which elapsed while the intensity of the fork decreased 10 db. was determined with a stop watch and divided into the 10 to obtain the decrement; *i.e.*, the decrease in sound intensity in decibels per second emitted by the fork. (Measuring the time interval which elapsed while the intensity decreased 10 db. and dividing as above resulted in less error than if an attempt were made to measure the interval over which the intensity decreased 1 db. Not less than 10 readings were made and averaged in obtaining the decrement of the fork to still further reduce the effects of hand tremors, observational and reaction time errors.)

The damping constant of the weighted Edelmann G_1 fork, with the weights adjusted near the ends of the tines so the

fork emitted a frequency of 256 cycles, was calculated to be 1.69 db. per second. It was found that the damping constant of this fork was considerably less than this when loosely supported in a fixed clamp. The difference in the decrements obtained when the same fork was supported in a clamp (0.83 db.), and when held in the hand (1.69 db.) indicates that the decrements of forks should be calculated only when they are held in the hand or clamped in a fixed support which is known to have the same damping effect on the fork as the hand. Hunter,[10] after a study of some of the factors which determine the decrements of tuning forks, concluded: "The decrement of tuning forks varies so much under different conditions that a very careful technique would be necessary to get uniform results for a given observer."

To obtain the decrement of this same fork while held against the head for bone conduction measurements, a crystal contact type vibration pickup, 3.5 cm. in diameter and 1 cm. thick, weighing 40 gm., was substituted for the microphone which had been used in obtaining the decrement for air conduction. This contact pickup was held against the forehead in a fixed position and with constant pressure by means of a narrow strip of Lastex rubber-dam which was tied behind the head.

When the Edelmann G_1 fork was held very lightly in the fingers with the end of the stem resting on the vertex of the cranium so that its own weight was practically the only downward pressure exerted, the decrement was found to be 0.96 db.; however, when the fork was held in contact with the head with a firm downward pressure, the decrement was 3.13 db. per second. The decrement of this fork, therefore, was found to vary from 0.96 to 3.13 db. when held in contact with the head, depending upon the magnitude of the pressure with which it was held against the skull. It appears contradictory that the decrement of the fork when balanced lightly on the head is less than the decrement of the same fork when held in the hand for air conduction measurements. This apparent discrepancy is due to the fact that when balanced on the head the fork was held very loosely in the fingers, whereas considerably greater damping effect is exerted by

the fingers on the stem of the fork when it is held in the horizontal position in the hand for air conduction measurements. Not all forks show such a wide variation between their air and bone conduction decrements. The value of the decrement is determined by the physical dimensions and characteristics of the material of which the fork is made.

The above calculations show that the decrement of a fork is anything but a constant except under a definite specified set of conditions. The determination of the decrement for air conduction measurements varies with the manner in which the fork is supported while obtaining the data necessary for the calculation. The bone conduction decrement also varies markedly with the pressure with which the fork is held in contact with the skull. It is apparent that gross errors will result in quantitative determinations of hearing acuity in terms of decibels by means of decrements of forks unless accurate methods of obtaining the decrements are employed for both the air and bone conduction measurements, and unless standardized techniques are adopted in the testing procedure.

Fowler[6] has described an ingenious "alternate placement" method or technique of performing tuning fork tests whereby the decrement of a given fork may be considered as having the same value for both air and bone conduction measurements. After the fork has been struck a constant blow, the end of the stem is pressed with deep firm pressure against the mastoid for one and one-half seconds and then the flat side of one of the tines held near and opposite the meatus for the same length of time. These alternate placements of the fork against the mastoid and then opposite the meatus, one and one-half seconds in each position, are continued until the sound is no longer heard. The patient is instructed to report "yes" or "no" when he hears or does not hear the fork each time it is held against the mastoid or opposite the meatus. The differences between the normal and abnormal hearing times for air and for bone conduction after the fork has been struck a constant blow, multiplied by the decrement of the fork when alternately placed as described above, gives the hearing loss for both air and bone conduction in decibels.

It is obvious that this alternate placement procedure automatically equalizes the decrement of the fork for both the air and bone conduction acuity measurements; however, to obtain a desirable degree of accuracy by means of this procedure, the decrement of the fork when alternately placed as above must be known and the fork should be energized with a constant blow. It is also necessary to hold the fork against the mastoid with the same pressure during successive skull placements, and keep constant the time intervals during which the fork is held alternately against the mastoid and near the meatus to prevent a change in the decrement of the fork when used according to the "alternate placement" method.

II. – THE "AIR-CONDUCTION BONE-CONDUCTION DIFFERENTIAL" OF AUDIOMETER VIBRATORS.

Because of the obvious difficulties involved in obtaining accurate quantitative bone conduction measurements with forks, attention next was directed to a study of certain physical characteristics of a new type of electrically activated bone conduction receiver or vibrator which was designed for use with the audiometer. This particular vibrator, Sonotone Type BR-66, was manufactured by the Sonotone Corporation, Elmsford, N. Y. The manufacturer states that it is constructed so that its energy output is practically free from variations due to the amount of pressure with which it is held against the skull. This type of vibrator is illustrated and described in detail by Jones and Knudsen.[11]

Since the outputs of audiometers are controlled by attenuation dials calibrated in decibels, the most direct method of obtaining comparable measurements of both air and bone conduction acuity appeared to be by means of the air and bone conduction attachments of audiometers; however, it is recognized that so-called bone conduction receivers, oscillators or vibrators have been subjected to adverse criticism which in some instances seemed to indicate that the results obtained with them were unreliable and even misleading.

Probably the most serious objection to audiometer vibrator attachments is the criticism that they may stimulate the

sense of hearing by air conduction rather than by bone conduction, especially at the higher frequency levels. This is due to the fact that the activated bone conduction vibrator may act as a sounding body which generates audible sound pressure variations in the air, which may stimulate the threshold for air conducted sound before the threshold for bone conduction is reached or stimulated. Under these conditions bone conduction measurements are impossible, and of course misleading if assumed to be true bone conduction measurements. On the other hand, it is generally known that most tuning forks which generate frequencies above approximately 1,000 cycles behave acoustically in this same manner and hence are open to this same objection. (It should be noted that in middle ear or conduction impairment, in which there is characteristically an air conduction loss but normal or near normal bone conduction, this objection to both tuning forks and audiometer vibrators is considerably minimized.)

The possibility of air-borne or radiated sound energy stimulating the sense of hearing by air conduction before the threshold for bone conducted sound is reached is considerably reduced or minimized in the vibrator used in this study because of its unique construction. A soft rubber cylinder is attached to the vibrator case or housing, its flaring free end surrounding but not touching the vibrating rod or piston. The flaring end of the rubber cylinder projects slightly beyond the tip of the piston so that when the piston is held against the flat or rounded bony surfaces of the head the intensity of the sound energy radiated by air from the vibrating piston is attenuated several decibels by the effect of the cylinder alone. This cylindrical rubber attachment offers very little pressure resistance to the application of the piston against the bones of the skull.

This receiver apparently was designed originally to be held in the hand, since it is not supplied with a headband or projections or recesses for the attachment of a headband. Holding the vibrator against the head with the hands, either by the patient or the examiner, seemed objectionable for the following reasons: due to tremors or fatigue of the arm and hand of the individual holding the receiver, the position of

the receiver on the mastoid might be shifted or the pressure with which it is held be changed, thereby producing variable and uncontrollable factors which would influence the results in unknown degree.

To minimize these sources of error, a special headband was constructed to hold the vibrator, which permitted it to be applied in such a manner that its position and pressure remained fixed throughout a test, and also enabled the same pressure to be exerted from patient to patient. The headband was padded with a heavy layer of felt to minimize the possibility of vibrational energy from the headband giving rise to bone conducted stimuli and to contribute to the patient's comfort while wearing it. This headband caused the piston of the vibrator to exert a pressure of approximately 410 gm. against the mastoid.

A high quality two-stage push-pull power amplifier was constructed for use between the Western Electric No. 2-A audiometer and the vibrator. This amplifier was designed to permit accurate impedance matching between the audiometer and the vibrator, and to give an additional amount of amplification which was needed to reach the bone conduction threshold in cases with severely decreased bone conduction.

The maximum amounts of amplification available by bone conduction above the normal bone conduction acuity thresholds at the different frequency levels with the audiometer and amplifier are as follows:

Frequency:	128	265	512	1,024	2,048	4,096	8,192	cycles
Maximum amplification above normal b.c. thresholds	50	60	70	80	90	65	65	db.

The vibrator was calibrated in the following manner: 21 university students (42 ears) with negative ear histories, with normal hearing for air conduction as determined with the Western Electric No. 2-A audiometer (within 10 db. of each of the eight test frequencies generated by this audiometer: 64, 128, 512, 1,024, 2,048, 4,096 and 8,192 cycles) and who did not lateralize the sound produced by the bone conduction vibrator at 512 cycles when it was placed against the midline of the head, served as calibration observers. (All

measurements reported in the present paper were made in a room so quiet that extraneous noises did not interfere with threshold measurements on normal ears.) The settings of the audiometer attenuation dial required to reach the bone conduction threshold for each frequency generated by the audiometer for the 42 ears were recorded. The attenuation dial of this audiometer is calibrated in steps of 5 db. in multiples of five. The averages of the settings to reach the threshold for each frequency were obtained, and these values, to the nearest multiples of five, designated as the normal thresholds for bone conduction for each of the eight different frequencies.

After obtaining the threshold values, the vibrator was subjected to experiment to ascertain if the normal thresholds as obtained above represented the true bone conduction stimulated thresholds, or if these threshold values were due to stimulation of the ear by air radiated and air conducted sound. In other words, does this vibrator stimulate the auditory threshold with air conducted or bone conducted sound energy? The answer to this question determines the limit of usefulness and accuracy of any device designed to test the acuity of bone conducted sound. In order to stimulate the threshold of hearing by bone conducted sound alone, the radiated air conducted sound pressure must be below the pressure value necessary to reach the threshold for air conducted sound while the bone conduction threshold is being stimulated. It is difficult to measure the number of decibels below audibility the air radiated sound pressure is when the threshold is being stimulated by bone conducted sound; however, it is possible to determine the number of decibels the bone conduction stimulus is above the bone conduction threshold when the sound pressure radiated through the air is just sufficiently great to stimulate the air conduction threshold.

Preliminary superficial investigation of the vibrator showed that it stimulated the bone conduction threshold rather than the air conduction threshold in normal ears because of the fact that when the bone conduction threshold was reached, lateral displacement of the vibrator from the mastoid by the hand, so that it was not quite touching the skin over the bone,

resulted in the cessation of all auditory stimulation for all of the frequencies generated by the audiometer.

To determine more accurately the difference in decibels between the intensity levels required to stimulate the threshold by air conduction and by bone conduction (the air conduction-bone conduction differential of the vibrator) at different frequency levels, further observational data were obtained by means of three of the individuals with normal hearing (six ears), whose thresholds did not vary more than 5 db. from the normal for both the air and the newly determined bone conduction thresholds in the following manner: After the vibrator had been adjusted in its customary position, a sponge rubber pad was inserted between the headband and the side of the head so that the flaring open end of the soft rubber cylinder surrounding the piston of the vibrator was displaced laterally about 1 cm. from its position against the mastoid. A circular laminated pad, slightly greater in diameter than the open end of the rubber cylinder, consisting of a layer of sheet rubber from an automobile inner tube glued to a flat piece of lead the same diameter and about 2 mm. thick was constructed. The rubber surface of this pad was then held in place against the free or open flaring end of the rubber cylinder, but not touching the piston, by means of a rubber band stretched around the vibrator case, thereby insulating acoustically the vibrating piston from the air surrounding it. This pad permits the rubber cylinder to attenuate the intensity of the sound radiated from the piston through the air, which is its normal function when in contact with the skin covering the mastoid bone. The settings of the audiometer attenuation dial then required to stimulate the air conduction threshold with the air radiated sound from the vibrator were determined and averaged for the six normal ears at the eight different test frequencies.

It was found that the differences between the radiated air conduction and the bone conduction thresholds varied from 25 to 15 db. over the test frequency range, the maximum difference occurring at the lower frequency levels. This "air-conduction bone-conduction differential" seemed sufficiently great to justify the use of the vibrator in further study of

pathological cases. This conclusion was confirmed when a few cases were tested who exhibited disproportionately decreased bone conduction; that is, greater losses for bone conduction than for air conduction. Such a finding would be impossible if the vibrator stimulated the threshold by air rather than by bone conduction. Threshold measurements of one of these cases will be shown later.

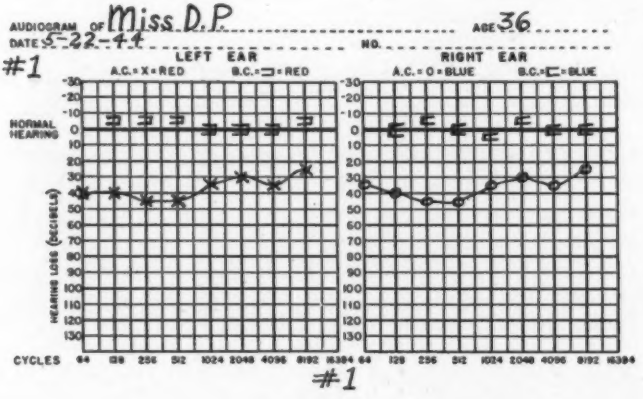
Another procedure for determining if any given type of vibrator used for bone conduction acuity measurements is perceived by the air or by bone conduction sound (particularly the higher frequencies) consists of retesting the bone conduction acuity of a given ear with the canal and concha filled with a heavy grade of vaseline or some other type of effective ear stopper or plug. The use of heavy vaseline as suggested above decreases the air conduction acuity approximately 30 db. Pohlman and Kranz[15] and Kelley and Reger[12] found that occlusion of the normal ear produces little or no effect on bone conduction acuity for frequencies above approximately 1,500 cycles, but increases bone conduction acuity from 15 to 20 db. for frequencies below approximately 1,500 cycles. We have found that occlusion of the canals of individuals with inner ear impairment produces the same bone conduction changes that occur in the normal ear, but produces no change in the bone conduction of individuals with middle ear impairment — an observation related to and in agreement with the Bing test; consequently, if bone conduction acuity tests before and after occlusion show that the bone conduction sensitivity remains unchanged for frequencies above approximately 1,500 cycles, it can be assumed that the air radiated sound does not stimulate the threshold before the bone conduction stimulus excites the bone conduction threshold.

III. – RESULTS OF AUDIOMETRIC MEASUREMENTS.

In the following audiograms both the air and bone conduction acuity curves are referred to the same normal base line. Before the bone conduction thresholds were determined, the vibrator was mounted on the middle of the forehead to ascertain in advance if the bone conducted sounds were referred

to one ear to the exclusion of the other (Weber's test). Only the bone conduction threshold value of the ear to which all the bone conducted sounds were lateralized, when lateralization occurred, are reproduced in the audiograms, although measurements were obtained from each mastoid, both with and without masking. The decision to present data only for the ear with the better bone conduction acuity is due to the fact that masking, with present available masking devices, is often misleading and uncertain, especially at the higher frequency levels. The results of attempted masking will be discussed later. The Weber, Schwabach and Rinne tests were also performed on each patient with the Edelmann G_1 and G_2 forks with the weights adjusted near the ends of the tines of the forks so that the G_1 fork emitted a frequency of 256 cycles and the G_2 fork a frequency of 512 cycles.

The following audiograms and fork findings are representative of typical measurements in various types of ear lesions:

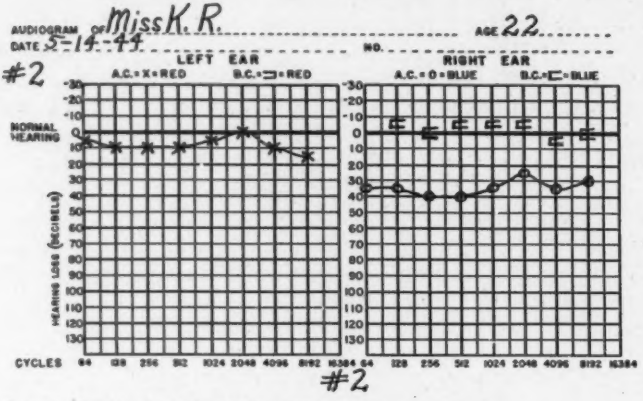


Case 1. Otosclerosis. Female, age 36.

Gradual progressive impairment. Both drums normal and both tubes patent.

Weber: Not lateralized. Schwabach: Normal bilateral. Rinne: Negative bilateral.

The audiogram of this patient shows a slightly greater loss for the low than for the high frequencies by air conduction bilateral. The bone conduction acuity is approximately normal from 128 to 8,192 cycles bilateral.

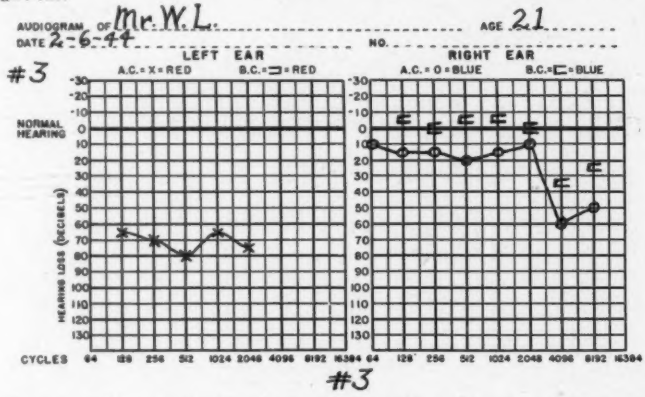


Case 2. Residual otitis media, right. Female, age 22.

Large central perforation in the right drum. Left ear normal.

Weber: Lateralized to the right, even when the forks were held in contact with the left mastoid. Schwabach: Normal in the right ear. Rinne: Negative in the right ear.

The audiogram shows normal bone conduction with a uniform air conduction loss of approximately 35 db. over the audiometer frequency range in the right ear.

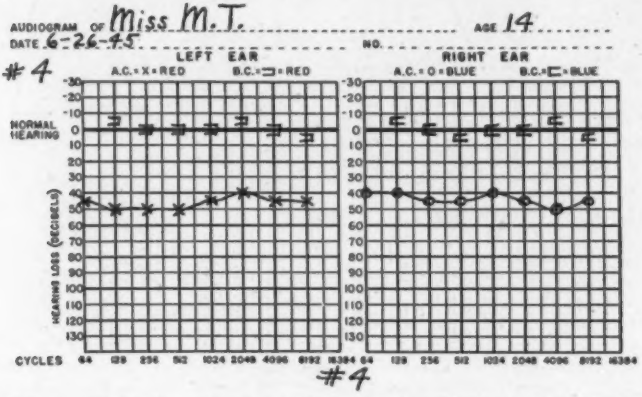


Case 3. Bilateral chronic otorrhea followed by radical mastoidectomies. Male, age 21.

Both tympanomastoid cavities well epithelialized and nonsuppurative four years after operation.

Weber: Lateralized to the right, even when the forks were held in contact with the left mastoid. Schwabach: Normal in the right ear. Rinne: Negative in the right ear.

The air and bone conduction acuity measurements reveal that the lesion in the right ear primarily is a conductive type, although there is a greater loss by both air and bone conduction for the two highest frequencies, indicating some inner ear involvement. This patient has the best air conduction acuity in the right ear ever observed by the writers in a four-year postoperative radical mastoid. The left ear exhibited considerably greater impairment for both ear and bone conducted sounds than did the right, indicating more extensive inner ear involvement on the left side.

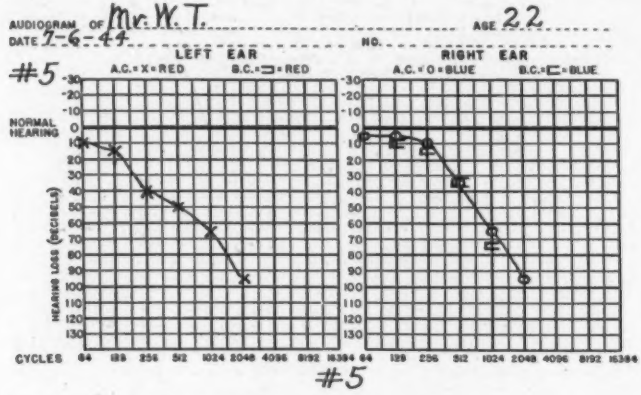


Case 4. Congenital atresia of the external auditory canals, bilateral. Female, age 14.

No significant ear history in addition to the congenital defect.

Weber: Not lateralized. Schwabach: Normal bilateral. Rinne: Negative bilateral.

The audiogram indicates normal bone conduction acuity bilateral with an approximate 45 db. loss for air conduction bilateral.

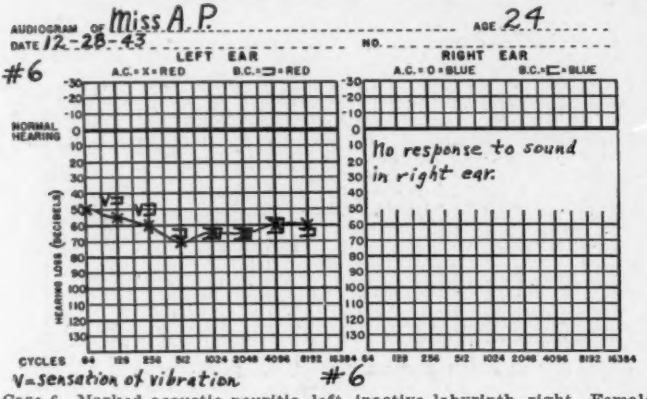


Case 5. Acoustic neuritis, bilateral. Male, age 22.

Both drums slightly atrophic and both tubes patent. The physical examination and history indicated congenital hearing impairment.

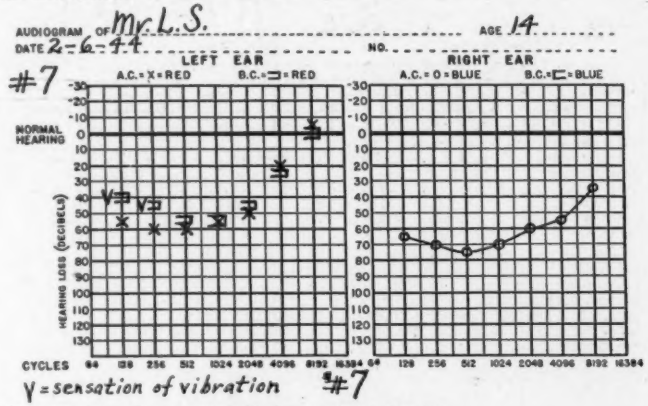
Weber: Lateralized to the right. Schwabach: Decreased three seconds for the 256 cycle fork, right. The 512 cycle was not heard by bone conduction. Rinne: positive for the 256 cycle fork, right.

As is apparent, this patient had approximately normal hearing for frequencies up to 256 cycles, above which the hearing loss increases the higher the frequency. The loss for bone conduction practically coincides with the air conduction loss in the right ear. The type of audiogram in which there is a greater loss for high than for low frequencies, and in which the loss for bone conduction is equal to the loss for air conduction is characteristic of inner ear impairment.


AUDIOGRAM OF Miss A.P. AGE 24
DATE 12-28-43 NO.
#6
LEFT EAR
A.C. = X = RED
B.C. = ⊐ = RED
RIGHT EAR
A.C. = O = BLUE
B.C. = ⊏ = BLUE
NORMAL HEARING
HEARING LOSS (DECIBELS)
No response to sound in right ear.
CYCLES 64 128 256 512 1024 2048 4096 8192 16384
V = sensation of vibration
#6

Case 6. Marked acoustic neuritis, left, inactive labyrinth, right. Female, age 24.

The 256 cycle fork was "felt" rather than heard and the 512 cycle fork did not elicit a sensation of any kind other than pressure against the mastoid. It was therefore impossible to obtain the Weber, Schwabach and Rinne reactions with the forks since they were not heard by bone conduction even when forced. The vibrator also elicited only sensations of feeling or vibration at 128 and 256 cycles. Frequencies from 512 to 8,192 were lateralized to the left with the vibrator. The loss in acuity was approximately equal for both air and bone conduction over this frequency range, and there was approximately as much loss for the low tones as for the high. It is generally believed that acoustic neuritis is characterized by a considerably greater loss for the high than for the low frequencies, as in Case 5; however, the results obtained on this and other patients seem to indicate that occasionally patients are seen with a type of acoustic neuritis in which there is as great a loss for the low as for the high frequencies by both air and bone conduction.

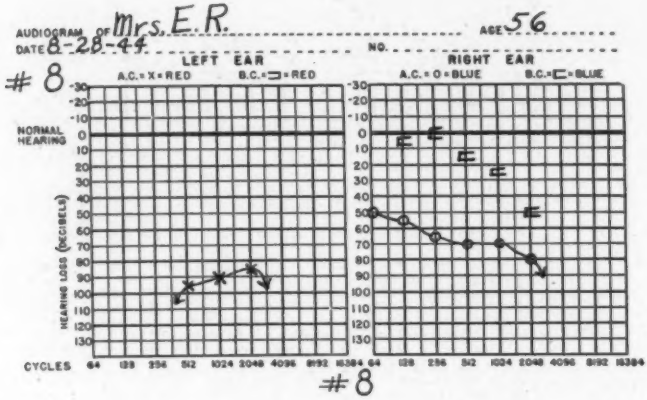


Case 7. Acoustic neuritis, bilateral. Male, age 14.

Both drums normal in appearance and both tubes patent. Hearing impairment since infancy. Tonsils and adenoids removed at age of five. Ear history and physical examination otherwise essentially negative.

Weber: The 256 cycle fork was perceived only as vibration and not sound, and the 512 cycle fork did not elicit any sensation other than that of contact

pressure, even when "forced" and held in contact with the mastoid. It was therefore impossible to obtain the Weber, Schwabach and Rinne reactions on this patient with forks. The audiometer vibrator produced a sensation only of vibration or feeling at 128 and 256 cycles but was perceived as sound at 512 cycles and for higher frequencies. On the basis of the relationship between the air and bone conduction threshold measurements, plus consideration of the negative ear history and physical examination, the diagnosis of acoustic neuritis seems most logical in this case, in spite of the fact that the air conduction hearing loss curve is the reverse of that usually seen in inner ear impairment.

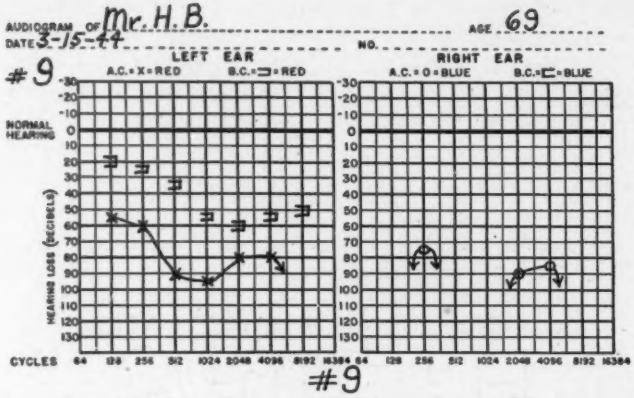


Case 8. Hyperplastic otitis media with nerve involvement, bilateral. Female, age 56.

Both tubes almost completely obstructed; right drum moderately retracted and left drum markedly retracted.

Weber: Lateralized to the right, even when the forks were held in contact with the left mastoid. Schwabach: Bone conduction normal for the 256 cycle fork and decreased six seconds for the 512 cycle fork in the right ear. Rinne: Negative in the right ear. (It was impossible to obtain the Schwabach and Rinne reactions in the left ear since the forks were heard in the right when held in contact with the left mastoid even when a masking noise at a level 100 db. above the normal threshold was placed over the right ear.)

This case illustrates the advisability of testing bone conduction acuity over as wide a frequency range as possible. This patient had normal bone conduction acuity for frequencies up to 256 cycles but decreasing bone conduction acuity for frequencies above this level.



Case 9. Hyperplastic otitis media with marked nerve involvement, bilateral. Male, age 69.

Marked retraction and scarring of both drums with partial obstruction of both tubes.

Weber: The 256 cycle fork was lateralized to the left ear, even when held in contact with the right mastoid. Schwabach: Decreased in left six seconds with the 256 cycle fork. The 512 cycle fork was not heard by bone conduction. Rinne: Negative in left. It was impossible to obtain the Schwabach and Rinne reactions in this patient's right ear since the 256 cycle fork was heard in the left ear when held against the right mastoid when a masking noise 100 db. above the normal threshold was held over the left ear.

The audiogram shows that this patient did not hear 512 and 1,024 cycles by air conduction in the right ear at the maximum intensity generated by the audiometer for these frequencies — 95 db. above the normal threshold. The audiogram consequently shows a "gap" between 256 and 2,048 cycles; however, when an amplifier was used between the audiometer and the earphone, the frequencies of 512 and 1,024 were heard at a level approximately 105 db. above the normal threshold.

IV. — THE MASKING OF BONE CONDUCTED SOUND.

It has been emphasized repeatedly in the literature that masking is more essential to eliminate errors in bone conduction than in air conduction acuity measurements. This is because of the fact that vibrational energy applied to any of the bones of the skull sets the entire skull in vibration, with little attenuation between the point of application of the vibrating sound source and other bones of the head. Dean[4] found that the attenuation or decrement of intensity from mastoid to mastoid ("across the head difference") was of the order of 10 db. or less.

The technique of effective and errorless masking, particularly of bone conducted sound, is not the simple procedure it is commonly inferred to be. The kind of masking noise used

usually introduces an unknown quantity, as different types of masking noises differ widely in frequency composition and in the relative intensities of the different frequencies of which they are constituted.

In addition to the type of masking noise used, the intensity levels at which the noise is applied to the ear to be masked presents an additional problem. If the noise exceeds a certain maximum permissible intensity it also may produce more or less masking in the opposite ear (the ear being tested), which would result in erroneous measurements. The intensity of the masking noise used should be indicated in terms of decibels above the normal threshold.

Some of the difficulties involved in masking bone conducted sound are illustrated by the attempts to obtain bilateral bone conduction measurements on Cases 3, 8 and 9. It was impossible to mask out all the bone conducted sound in the ear to which it was lateralized in each of these cases, with a masking noise 100 db. above the normal threshold as produced by the Western Electric No. 5-A buzzer audiometer.

Because of the apparent complexities involved in accurate and errorless masking, the writers wish to avoid erroneous conclusions in the present paper by misinterpretation of masked bone conduction thresholds until further study of this aspect of bone conduction measurement has been completed. As previously stated, only the bone conduction threshold values of the ear to which all the bone conducted sounds were lateralized, when lateralization occurred, are reproduced on the audiograms in the present paper, in order to avoid artifacts in measurement.

V. – THE WEBER, SCHWABACH AND RINNE TESTS WITH THE BONE CONDUCTION VIBRATOR.

The results obtained with the vibrator in no way contradicted or disagreed with the fork findings. The vibrator, when placed on the midline of the head, was lateralized (Weber test) to the same side as the forks. As a matter of fact, the vibrator proved more effective in the Weber test in a few instances because of its greater vibrational energy out-

put, especially for frequencies above approximately 512 cycles. For example, it was impossible to obtain the Weber reaction on Case 7 with forks because this patient "felt" rather than heard the 256 cycle fork and perceived no sensation from the 512 cycle fork other than the pressure of the stem against the mastoid bone. With the vibrator, the low frequencies up to and including 256 cycles were "felt" rather than heard, but at 512 cycles and above, the frequencies reproduced by the vibrator were heard and lateralized to the left ear.

Any technique designed to measure bone conduction acuity may be regarded as a variation or form of the Schwabach test, no matter the type of instrument used to apply vibrational energy to the bones of the head; consequently, bone conduction acuity data obtained with the vibrator may be regarded as Schwabach test measurements. Here again, the wider frequency and intensity ranges of the vibrator demonstrated that it possessed certain advantages not common to the forks. The 256 cycle fork elicited only sensations of feeling or vibration in patients 6 and 7, while neither of these patients perceived any sensation other than pressure against the mastoid from the 512 cycle fork. Shall it be concluded from the results with forks that these patients had complete loss of hearing by bone conduction? Similar findings formed the basis of an article by Adams[1] on "Apparent Complete Loss of Bone Conduction in the Presence of Fair Hearing by Air Conduction." The results of testing the bone conduction acuity of patients 6 and 7 with the vibrator at 512 cycles and above, at which frequency levels much more vibrational energy can be utilized without stimulating the threshold of feeling by bone conduction than at lower frequencies, showed that these patients do have hearing by bone conduction in spite of the fact that none could be demonstrated with the forks.

Notwithstanding the fact that the vibrator possesses a greater usable frequency and intensity range than the forks, by far its greatest advantage lies in the directness and accuracy with which the air and bone conduction acuity measurements can be compared with each other. By referring both air and bone conduction threshold values to the same "nor-

mal" base line, the examiner can tell at a glance if the bone conduction is normal, increased or diminished, and if it is equal to, better or possibly worse than the air conduction — in measurement terms which permit direct quantitative comparisons between them.

It may appear that the vibrator can contribute little if anything to the technique and interpretation of the Rinne test; however, careful consideration of the threshold measurements for both air and bone conduction obtained with the air conduction receiver and the bone conduction vibrator in terms of measurements that can be compared directly with each other shows that these data reveal the very information sought in the Rinne test. As is well known, the outcome of the Rinne depends upon the relative acuity of the air and bone conduction thresholds. For example, if threshold measurements reveal that there is considerable reduction in air conduction acuity and the Schwabach indicates that the bone conduction is approximately normal, it can be predicted with certainty that the Rinne will be negative. If, on the other hand, the air conduction and the bone conduction acuity are normal or if both are reduced an equal amount, it can be predicted with equal certainty that the Rinne test will be positive.

Sonnenschein[17] wrote concerning the Rinne test: "We have felt that this tuning fork test is probably the most valuable of all, in that it furnished so much information regarding the localization of the lesion of hearing by giving the ratio of air to bone conduction. . . . The Rinne test as usually performed gives us the ratio between bone and air conduction and furnishes us most valuable information. . . ." Sonnenschein[17] described eight different typical relationships (or ratios) between air and bone conduction as revealed by the Rinne test as follows:

"*1.* Two forms of the positive Rinne: *a.* Positive, in which the air conduction is much longer than the bone conduction, but both are normal in duration; this is the normal positive Rinne. *b.* Positive, air conduction longer than bone conduction but both of them shortened as compared with the normal

duration; this form is found in internal ear trouble, with impairment of hearing. *2.* Three forms of the negative Rinne: *a.* Bone conduction considerably increased and longer than the air conduction, which latter is moderately diminished; this form is found in the ordinary middle ear disease. b. Bone conduction longer than air, but both diminished as compared with the normal; here we often find a combination of internal and middle ear disease. *c.* Bone conduction greater than air but both very much shortened; this form occurs in very far advanced ear disease, because air conduction is then lost more rapidly than the bone. *3.* "Indifferent" Rinne. Of this there are two varieties: *a.* Air and bone conduction of equal length because air conduction is slightly diminished and bone conduction slightly increased; hearing is usually good in this form, in which a slight middle ear affection is usually the condition present. *b.* Air and bone conduction equal in duration but both of them much shorter than the normal; in this form the hearing is very poor, as this reaction is usually found in cases of serious internal ear disease. *4.* "Infinite" Rinne. If not heard at all by air but somewhat by bone, we have the so-called infinitely negative Rinne; this is often found in cases of far advanced internal ear disease. While it seems almost impossible to have a positively infinite Rinne. that is, heard somewhat by air but not at all by bone, still we have found it in two of our cases."

Bunch[2] concluded: "The Rinne test is, in final analysis, a method for comparing the patient's ability to hear by air conduction and by bone conduction. Similar comparisons can be made with the audiometer and with the air-conduction and bone-conduction receivers. Certain variables which arise when this test is done with the tuning forks can be eliminated if the audiometer be used."

The Rinne test, as usually conducted with forks, at best gives only a qualitative indication of the magnitude of the ratio or relationship between the air and bone conduction acuity. As previously indicated, by referring both the air and bone conduction threshold values to the same normal base line in the same quantitative terms of measurement, the examiner

can tell at a glance if the bone conduction is normal, increased or diminished, and if it is equal to, better or possibly worse than the air conduction. When these data are available, the Rinne test can contribute nothing further of value.

It can be demonstrated that the lateralization of the Weber reaction often can be predicted if the bone conduction acuity of the two ears can be determined separately, since the Weber usually is lateralized to the ear with the better bone conduction acuity. This can be confirmed by the normal hearing individual who does not definitely lateralize a fork to either ear, by closing one of his external canals with a finger. Such occlusion increases the bone conduction acuity of the normal ear which is closed and lateralizes the sound of the fork to that side.

For the above reasons the writers regard the Schwabach test as the most fundamental and significant of the bone conduction tests. Both the Weber and Rinne are secondary or derived tests. The results obtained with the Weber usually depend upon the difference in bone conduction acuity between the two ears, and the outcome of the Rinne depends upon the relative acuity between the air and bone conduction thresholds. The Rinne test is merely a rapid "rule of thumb" method for obtaining a qualitative indication of the relationship between the air and bone conduction acuity.

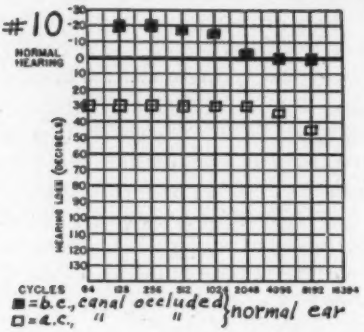
VI. – THE GELLÉ, BING AND OCCLUSION TESTS WITH THE VIBRATOR.

The Gellé test for stapes ankylosis usually is not regarded as a highly accurate test. Among the factors contributing to the indecisiveness of the test are the following: *1.* the intensity of the fork itself gradually decreases with time and hence is not a constant stimulus, and *2.* confusing fluctuating loudness changes may occur as the result of tremors of the hand holding the fork against the mastoid bone. The vibrator, when adjusted properly, provides a constant intensity sound source at any desired intensity level, and hence provides a more ideal stimulus tone during the test procedure.

The vibrator also may be utilized to advantage in the Bing test, which should be performed only in an exceedingly quiet room. The vibrator is properly adjusted in contact with the mastoid bone and the test tone (1,024 cycles or lower, preferably 512 or 256 cycles) presented at a level several decibels above the patient's threshold so he can identify the sound later near the threshold level. The intensity of the sound is then decreased until it is just below the threshold; that is, no longer heard. The external auditory meatus of the ear against whose mastoid the vibrator is placed (if the sound is lateralized to that ear) is closed gently with the finger. If the sound is heard after closure of the canal, the test is positive, indicating a normally functioning middle ear mechanism. If the sound is not heard again after closing the canal, the test is negative, indicating middle ear impairment. A slight variation in technique consists in presenting the tone at a constant level several decibels above the patient's threshold while the canal is alternately closed and opened. If the sound is louder while the canal is closed than while open, the test is also positive; no change in loudness, negative.

A quantitative method of performing a modification of the Bing test is the following: Obtain the bone conduction acuity of the patient with the vibrator in the usual manner. Then, without touching the vibrator, so its position and pressure remain unchanged, fill the external auditory meatus and concha with vaseline and repeat the bone conduction acuity measurements. If the patient possesses a normally functioning middle ear mechanism, that is, if his tympanic membrane and ossicular chain possess their normal motility (which is the case in the normal ear and in the patient with inner ear impairment) the bone conduction acuity will be increased approximately 15 db. for frequencies below about 1,500 cycles, remaining unchanged for higher frequencies. On the other hand, if such occlusion produces no change in the bone conduction acuity, a middle ear lesion exists. This test is exceedingly delicate. Slight middle ear involvement, in which the air conduction acuity shows but little loss, is sufficient to result in a negative occlusion test.

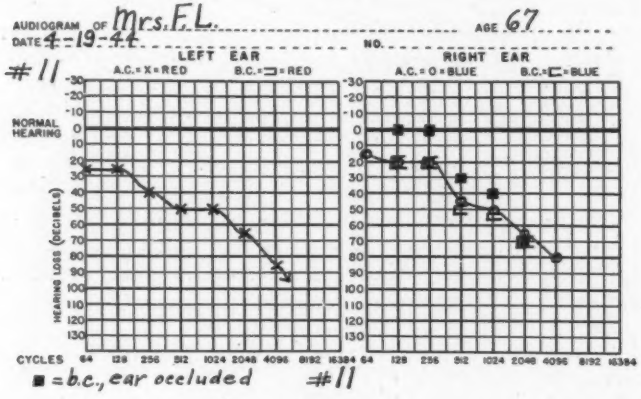
Audiogram 10, below, shows the effect of occlusion on both



Case 10.

the air and bone conduction acuity of the normal ear.[12]

Audiogram 11 shows the result of occlusion of the ear of a patient with advanced nerve impairment.



Case 11.

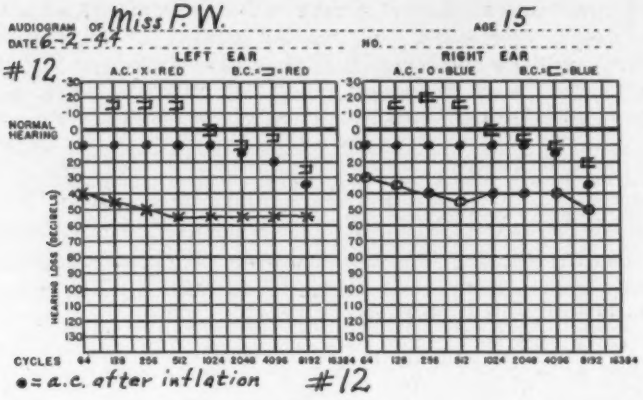
Note that the bone conduction acuity was increased only for the frequencies below 2,048 cycles after occlusion. Occlusion had no effect on the bone conduction acuity of patients 1, 2, 3, 8 and 9 with middle ear or mixed types of impairment.

As previously indicated, tests of the bone conduction acuity before and after occlusion present a method for determining if a given bone conduction test instrument is perceived by air radiated or bone conducted sound, particularly for frequencies above about 1,500 cycles. Occlusion decreases the air conduction acuity from 30 to 40 db. for the higher frequencies but produces practically no bone conduction change above 1,500 cycles. If more power is required to stimulate the bone conduction threshold with the ears occluded than when open, evidence is obtained which indicates that the bone conduction vibrator stimulates the threshold of hearing of the open ear by air rather than by bone conducted sound.

VII – INCREASED BONE CONDUCTION ACUITY.

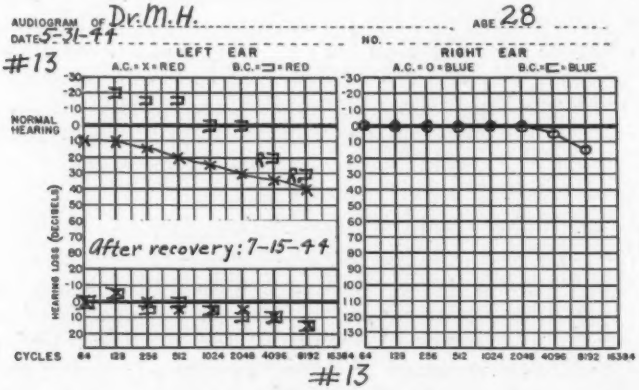
Is increased bone conduction acuity an actual clinical entity? The earlier otologists reported such a consistently high incidence of increased or prolonged bone conduction in patients with middle ear pathology that the finding of increased bone conduction became one of the most important functional diagnostic criteria in middle ear impairment. Within the past few years, however, during which more and more emphasis has been placed on the testing of auditory acuity in quiet or soundproof rooms, relatively few cases of increased bone conduction have been observed. As a matter of fact, several investigators have reached the conclusion that increased bone condition is an artifact, being explained by the masking effect of room noise on the acuity of the examiner, which is often utilized as the normal basis for comparison in the performance of the Schwabach test with forks. The threshold of the patient with middle ear impairment is not shifted by the masking effect of the room noise unless his hearing loss is slight or the room noise level exceedingly high.

Bunch[2] was of the opinion that increased bone conduction acuity is not a clinical entity, being due to the masking effect of the room noise on the acuity of the examiner. Bunch[2] states: "It is unfortunate indeed for otology that these teachers failed to recognize the necessity for doing the hearing tests in a quiet place where the background noise would not interfere with the hearing of either the patient or the examiner."


AUDIOGRAM OF Miss P.W. AGE 15
DATE 6-2-44 NO.
#12
LEFT EAR
A.C. = X = RED B.C. = ⊐ = RED
RIGHT EAR
A.C. = O = BLUE B.C. = ⊏ = BLUE
NORMAL HEARING
HEARING LOSS (DECIBELS)
CYCLES 64 128 256 512 1024 2048 4096 8192 16384
● = a.c. after inflation #12

Case 12.

Audiogram 12 shows increased bone conduction for frequencies below 1,024 cycles. It is interesting to note that the bone conduction acuity remained unchanged after inflation, although inflation resulted in exceptionally marked but temporary improvement in air conduction acuity.


AUDIOGRAM OF Dr. M.H. AGE 28
DATE 5-31-44 NO.
#13
LEFT EAR
A.C. = X = RED B.C. = ⊐ = RED
RIGHT EAR
A.C. = O = BLUE B.C. = ⊏ = BLUE
NORMAL HEARING
HEARING LOSS (DECIBELS)
After recovery: 7-15-44
CYCLES 64 128 256 512 1024 2048 4096 8192 16384
#13

Case 13.

Audiogram 13 shows increased bone conduction acuity during an episode of acute otitis media. The air conduction of

the involved ear shows a progressively greater loss with increasing frequency, indicative of inner ear involvement. This was corroborated by the bone conduction acuity at 4,096 and 8,192 cycles, where the losses were in excess of 20 and 30 db. respectively.

After uneventful recovery, about six weeks later, the patient's bone conduction acuity decreased to normal and the air conduction increased to normal.

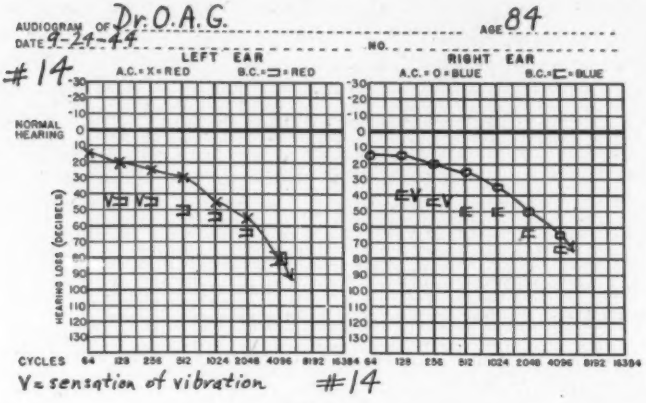
Hulka[9] reported: "It was found that the tympanic inflammation increased the bone conduction of low tones and simultaneously decreased the bone conduction of high tones in 29 of the 38 inflamed ears. . . . After healing, the low tone end of the curve went down, while the high tone end went up. . . . On the graph this change had the appearance of a seesaw movement of the bone conduction curve."

We have seen several cases of increased bone conduction acuity which parallel the audiograms of Cases 12 and 13 since routinely testing bone conduction acuity with the audiometer vibrator, and are of the opinion that increased or prolonged bone conduction acuity is a definite clinical entity, but of relatively rare occurrence. At the present time it does not seem advisable to hazard a guess about the percentage of cases of middle ear impairment with increased bone conduction. Available data indicate that increased bone conduction in middle ear pathology in general is of sufficiently rare occurrence to be regarded as the exception rather than the rule.

To what extent should the bone conduction acuity be increased before it can be considered an increase of pathological significance? The answer to this question is an open one, awaiting additional work and discussion; however, as the result of study of the effect of occlusion on bone conduction acuity of the normal ear, and observation and study of increased bone conduction on pathological cases, it seems reasonable to assume that bone conduction acuity should show an increase above normal of at least 15 db. for two or more adjacent octave intervals for frequencies below 1,500 cycles in order to be considered pathologically significant. The writ-

ers have not seen an increase this great for any two adjacent octaves above 1,500 cycles.

VIII – DISPROPORTIONATELY DECREASED BONE CONDUCTION ACUITY.



Case 14.

Audiogram 14 presents a case with disproportionately decreased bone conduction — a somewhat greater loss for bone than for air conduction— a paradoxical finding. As a matter of fact, this patient did not perceive the stimuli from the vibrator as sound but as vibration or feeling at 256 cycles and below.

The patient is a male, age 84, with negative ear history except for gradual progressive hearing impairment. Both tubes were patent and both drums slightly atrophic and retracted.

Ciocco[3] found that: "The incidence of those with shortened bone conduction increases with advancing age. . . ." We have tested many individuals in the seventh and eighth decades who did not show disproportionately decreased bone conduction.

The measurements on this case demonstrate that the vibrator used in this study was perceived by bone rather than by

air conduction. If such were not the case, measurements showing greater losses for bone conduction than for air conduction would not be obtained.

IX – THRESHOLD OF FEELING FOR BONE CONDUCTION.

The possibility that low frequency forks might excite the sense of vibration — pallesthesia — rather than the sense of hearing, especially in cases with decreased bone conduction, has been recognized for several decades. Naturally, audiometer bone conduction attachments produce similar effects. Inspection of the audiograms of Cases 6, 7 and 14 indicates that the vibrator used stimulates the sense of vibration at 128 and 256 cycles at approximately 50 and 55 db. respectively above the normal bone conduction acuity thresholds at these frequency levels. The present equipment does not possess sufficient amplification and power to stimulate the threshold of pallesthesia at 512 cycles and higher.

A distinction should be made between the threshold of feeling arising from the stimulation of free nerve endings and contact receptors of the tympanic membrane by high level sound pressures, and the pallesthesia resulting from placing a vibrating object against a subcutaneous bony prominence of the body.

X – RELIABILITY OF AUDIOMETER BONY CONDUCTION VIBRATORS.

Measurement of bone conduction acuity with audiometer vibrators has received much justifiable criticism in the past. Many early vibrators stimulated the air conduction rather than the bone conduction threshold at frequency levels above 1,000 cycles, especially in the normal ear and in individuals with inner ear impairment. The amplitude of vibration or energy output also varied somewhat with changes in the pressure with which certain vibrators were held in contact with the skull. For these and other reasons, the results obtained with many vibrators were inaccurate and even misleading.

In spite of the imperfections of audiometer bone conduction vibrators, the use of the audiometer for the measurement of bone conduction acuity is receiving more and more atten-

tion. When properly constructed, calibrated and used, the results obtained with the audiometer and forks exhibit consistent agreement over the limited frequency range common to both forks and audiometer.

McNally, Erickson, Scott-Moncrieff and Reeves[13] stated that: "Bone conduction as tested by the audiometer was not found to be any more or any less reliable than when tested by the tuning fork." Senturia and Thea[16] concluded:

"Complete bone conduction curves from 256 d.v. to 8,192 d.v. are desirable. For practical purposes the tones 512 d.v., 2,048 d.v. and 4,096 d.v. furnish a satisfactory sampling of bone transmitted sound.

"The most vulnerable portion of the bone conduction curve appears to be located at 4,096 d.v.; the most resistant, below 1,024 d.v.

"The use of a single frequency or one tuning fork for bone conduction interpretation may yield serious errors.

"Decrease of bone conduction in the high tones parallels the air conduction loss occurring with increasing age and accompanying pathological changes.

"If testing is carried on by trained personnel and under soundproof conditions, consistent results are obtainable; and if the audiometer is calibrated and checked at frequent intervals, accurate interpretation can be made. . . ."

There are at least two studies in the literature which give considerable information on the accuracy or variability of bone conduction acuity measurements on individuals with "normal" hearing. Greenbaum, Kerridge and Ross[7] tested the bone conduction acuity of 100 medical students in the sound-testing room of the Royal Ear Hospital. The tests were conducted with two different audiometers: a Western Electric Type 2-B and an English Mains instrument, Type 2-BE. The Western Electric Type D-80904 bone conduction receiver was used on each audiometer.

The results of the measurements are summarized in terms

of the standard deviation or SD, which is the most reliable of the statistical measures of variability.* The above authors found the following SD for bone conduction acuity over the indicated frequency range:

Frequency	64	128	256	512	1,024	2,048	4,096	8,192	cycles
SD	6.8	7.95	6.5	7.4	8.2	6.8	7.1	7.0	± db.

The National Health Survey, Hearing Study Series,[14] presents comparable data on both air and bone conduction acuity measurements on 1,242 individuals. Seventeen different Western Electric 2-A audiometers were employed in the tests. The air conduction measurements were made with 17 552-W receivers, and the bone conduction measurements were made with 19 700-B receivers.

"This bulletin presents a selected case of auditory acuity measurements for both air and bone conduction, which is considered to represent normal hearing in the population in terms of the scale units and intensity calibration incorporated in the Western Electric 2-A audiometer, with its associated 552-W air conduction receiver and 700-B bone conduction receiver. The distributions of measurements are for 1,242 persons, who were drawn at random from the general population, and whose air conduction audiograms do not exceed a variation of 20 db. on eight tones, spaced at octave intervals, from 64 to 8,192 cycles.

". . . The standard deviation of the distributions of measurements by air conduction vary from 5.9 to 6.8 db., and those by bone conduction vary from 7.4 to 8.7 db. These measures of dispersion not only reflect the variance due to differences between individuals but also that arising from all factors of variability associated with 17 audiometers, 17 air conduction receivers, 19 bone conduction receivers, 17 environmental conditions and 31 different audiometricians."

The following table shows the SD for both air and bone conduction from 256 to 8,192 cycles, obtained in the National

*In a "normal" distribution or "normal" frequency curve, the SD, when measured off above and below the average marks the limits of the middle 68.26 per cent (roughly the middle two-thirds) of the distribution. An SD of 7 db at 8,192 cycles, for example, indicates that 68 per cent of the measurements at 8,192 cycles fall within an extreme variation of 14 db, either 7 db. above or below the average or "normal" threshold value.

Health Survey on 1,242 ears for bone conduction and 2,484 ears for air conduction:

Frequency	256	512	1,024	2,048	4,096	8192	cycles
SD (B.C.)	7.4	7.4	7.5	8.3	8.5	8.7	db.
SD (A.C.)	6.0	6.0	5.9	6.4	6.7	6.8	db.

Inspection of the table reveals that the SD for bone conduction is only slightly greater than that for air conduction, indicating that the bone conduction measurements on normal ears showed only a slightly greater deviation from the theoretical normal curve than the comparable air conduction measurements.

After a study of the physical characteristics and performances of two different types of commercially available bone conduction receivers, Grossman and Molloy[8] concluded:

"It has been shown that no definite values in any measure, decibels or otherwise, can be attributed to the curve arrived at by present methods of clinical audiometry. Should otologists discard the measuring of bone conduction by said methods? We believe that the audiometric bone conduction threshold curve has a clinical value for purposes of establishing a diagnosis. The trend of the curve as well as its general position in the audiographic chart will permit the experienced otologist to utilize it as a symptom of hearing impairment if it has been arrived at by means of an audiometer with which the investigator is familiar. He must realize, however, that such a curve does not represent a measurement of the forces applied. It should be used as a rule of thumb based on clinical experience only, similar to the rules of thumb known as Weber, Rinne and Schwabach tests.

"The investigation presented exhibits some of the sources of error which occur in present methods of audiometric testing of hearing by bone conduction. They are in the bone conductor itself and not in a particular manner of testing or in psychologic factors."

The performance characteristics of the type of vibrator used by us were not subjected to analysis by Grossman and Molloy. We discarded the vibrators studied by them in favor of the one used in this investigation because of its superior

mechanical construction and performance. Their conclusions, of course, do not apply to future developments in audiometer bone conduction testing devices or attachments, and it is hoped that their criticism will result in the development of more reliable audiometer vibrators rather than a loss of interest and reliance on audiometer bone conduction measurements.

The writers of the present paper have obtained the air and bone conduction acuity measurements with both forks and the audiometer on our patients for the past few years and have not observed any discrepancies between the measurements made by the different methods.

It is our opinion that bone conduction vibrators, when properly built, calibrated and used, contribute so many advantages to the accurate testing of bone conduction acuity in units which permit direct comparison with the air conduction acuity that every encouragement possible should be given to their future development and use. Mechanical design that will stand up under continued and rough usage without change in calibration, extension of the frequency range to values near or coincident with the normal upper limit of audibility, freedom from overtones, freedom from effects of difference in pressure with which the vibrator is held against the head, and a wide "a.c.-b.c. differential" are among the many desirable characteristics of vibrators which may be anticipated. A headband which would insure that the vibrator to be held against the mastoid (or other bones of the head) with the same pressure from patient to patient also seems a highly desirable accessory.

XI – INTERPRETATION OF THE RELATIONSHIPS BETWEEN AIR AND BONE CONDUCTION ACUITY THRESHOLD MEASUREMENTS.

As the result of careful comparisons of bone and air conduction acuity measurements obtained with both the audiometer vibrator and forks on patients with different types of ear pathology, the following relationships or diagnostic criteria are applicable to the audiometric measurements:

1. If the air conduction acuity is below normal but bone

conduction normal or possibly increased, the patient has a middle ear lesion.

II. If the patient has the same loss for both air and bone conducted sound, or possible disproportionately decreased bone conduction, the loss is the result of an inner ear lesion, especially if the history, physical examination and motility tests (Gellé, Bing or occlusion) demonstrate the absence of middle ear involvement.

III. If the patient has a loss for both air and bone conducted sound, with a greater loss for air than for bone conduction, the impairment is due to a mixed lesion, indicating simultaneous middle and inner ear involvement.

It is intended that the above three statements or rules be regarded as broad generalizations only. The accurate testing of bone conduction acuity over wide frequency and intensity ranges is in its infancy. There is an acute need for additional research on the factors influencing the accuracy of bone conduction measurements, as well as clinical interpretation of the results of such measurements, especially in relation to fenestration surgery and acoustic insult as the result of concussion and blast injury to the ear.

XII – CONCLUSIONS.

I. The results of bone conduction measurements obtained with the vibrator used in this study in no way contradicted or disagreed with the fork findings: The vibrator demonstrated superior or desirable characteristics in the following respects:

A. The vibrator makes possible the testing of bone conduction acuity in terms of measurement which enable direct immediate comparison between the air and bone conduction acuity.

B. The vibrator permits the testing of bone conduction acuity (Schwabach) over wider frequency and greater intensity ranges than are possible with the forks.

C. Air and bone conduction acuity determinations obtained in the same measurement terms give the information sought

in the Rinne test over wider frequency and intensity levels than are possible with the forks.

D. The Weber test can be performed over wider frequency and intensity levels than with the forks.

E. The Gellé, Bing and occlusion tests can be conducted with the vibrator with a higher degree of accuracy than is possible with forks.

II. Increased bone conduction is a real phenomenon but is of such rare occurrence that it may be considered the exception rather than the rule in cases of middle ear impairment.

III. Increased bone conduction is of most frequent occurrence for frequencies below 1,500 cycles.

IV. A given patient may exhibit both increased and decreased bone conduction in the same ear simultaneously — increased for low and decreased for high frequencies.

V. It is more difficult to achieve effective masking for bone conduction than for air conduction measurements.

VI. Properly constructed, calibrated and used bone conduction vibrators possess sufficient reliability and accuracy to justify their use.

VII. The development of such a vibrator for general use will constitute a progressive advancement in the functional examination of hearing.

The writers gratefully acknowledge the loan of the bone conduction vibrator by the Sonotone Corporation, Elmsford, New York, which made this study possible.

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MISSISSIPPI VALLEY MEDICAL SOCIETY TO MEET IN ST. LOUIS, SEPT. 25, 26, 27, 1946.

The eleventh annual meeting of the Mississippi Valley Medical Society will be held Sept. 25, 26, 27, 1946, at the Hotel Jefferson in St. Louis. Due to the fact that no meeting was held in 1945, all the officers of the society have been retained for another year. These include the president, Dr. Grayson L. Carroll, of St. Louis; president-elect, Dr. Walter A. Sternberg, of Mt. Pleasant, Iowa; first vice-president, Dr. Louis H. Jorstad, of St. Louis; second vice-president, Dr. Elmer E. Nystrom, Peoria, Ill; third vice-president, Dr. E. J. Lessenger, New London, Iowa; secretary-treasurer, Dr. Harold Swanberg, Quincy, Ill.

AERO-OTITIS EXTERNA.

(A SYNDROME RESULTING FROM THE USE OF EARPLUGS IN FLIGHT.)*

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St. Louis, Mo.

INTRODUCTION.

The rapid progress made in the field of aviation has brought with it many new medical problems. Among these is aero-otitis externa, a syndrome resulting from the use of ear plugs by flying personnel for the protection of hearing against the intense ambient noises found in military training and combat aircraft.

The problem of noise is not so serious in commercial aircraft, which can afford the luxury of a great deal of sound insulation. In most military aircraft, however, noise levels are high enough to mask radio communication and may be sufficient to cause temporary hearing losses which interfere with the hearing of spoken voice during flights and for a variable period after the completion of a flight.[1,2,3]

If the flyer shows little susceptibility to acoustic trauma, then headphones, cotton, or both, will suffice to protect him. With the very large increase in the number of flying personnel, however, there will be more and more persons who are susceptible to the injurious effects of aircraft noise and, therefore, need additional protection against the possibility of permanent loss of hearing.

In the matter of the protection of his hearing, the pilot or crew member has several choices: *1.* He may depend solely upon his headphones to screen out the ambient noise (it should be noted that headphones offer no protection against electrically generated noises); *2.* he may make use of the readily available and commonly used absorbent cotton folded

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and rolled into the form of an ear plug; *3.* he may seek more ear protection by the use of a molded neoprene imperforate plug, a wax impregnated cotton, self-molding type, or a molded rubber perforate type. Representative samples of each of these have been tested in this and other laboratories.

The development and use of various new devices for the protection of hearing in aircraft raised the important question: Will flying personnel, subject to rapid changes of air pressure, encounter difficulty when wearing ear plugs which prevent equalization of pressure in the external ear?

Some such difficulty is to be expected by analogy with the conditions in the middle ear where pressure differences between the outside air and the tympanic cavity result in the syndrome of vascular trauma which has been called aero-otitis media.[4] The introduction into the ear canal of a non-perforated ear plug (or a perforated plug in which the airflow through this perforation is inadequate) results in the formation of an artificially closed chamber external to the tympanic membrane which is comparable to the middle ear cavity. The air leak which may or may not exist around the ear plug may be likened functionally to the Eustachian tube, since both are channels for airflow from their respective cavities to the outside atmosphere; therefore, one might expect, as anticipated also by another observer,[5] that the same pressure differentials which, during descent from altitude, give rise to aero-otitis media, might cause a similar condition in the artificially closed external auditory canal.

As will be described in more detail below, a syndrome of vascular trauma has been observed in ears occluded by ear plugs during flights in the altitude chamber and in aircraft. By reason of the apparent close casual similiarity of this syndrome with aero-otitis media, the name aero-otitis externa has been chosen by the writers.

The experiments herein reported were designed primarily as a study of the influence of ear plug type and altitude, upon the incidence rate of aero-otitis externa. Answers to three practical questions were sought: *1.* Do ear plugs of various kinds produce serious ill-effects at high altitude? *2.* What

type of ear plug, if any, may be safely worn for the protection of hearing by high altitude flying personnel? *3*. At what altitude do ear plugs begin to cause trouble?

METHODS.

All experiments were performed with volunteer enlisted trainees who were awaiting assignment to pilot training. Prior to the tests, all subjects filled out questionnaires concerning upper respiratory diseases, and were examined for ear pathology. Measurements of the external orifices were made with circular, standard-sized rods, and the size judged by the smallest size rod which gave a "pressure-suction" fit. One or both ears of each subject were then fitted with plugs of appropriate sizes. (With angulated and tapered canals it was usually not possible to fit plugs as large as indicated by the "pressure-suction" criterion. This was particularly true of the molded rubber perforated types.) Those who were to take flights in the altitude chamber were given instruction and demonstration in the technique of middle ear ventilation. Above 10,000 feet, oxygen masks were worn, usually with light summer helmets and no other ear covering. Subjects were instructed to remove or loosen the plugs in the event of ear pain or discomfort during the descent from altitude. Experiments were performed with groups of 12 to 16 men and the various types of ear plugs distributed more or less equally within each group.

A total of 490 subjects (980 ears) participated in this investigation. Experiments were conducted at ground level (56 subjects), 10,000 feet (104 subjects), 24,000 feet (204 subjects) and 38,000 feet (126 subjects). Standard pressure rates of ascent and descent were used, the ascent rate being 4,000 feet per minute, and the descent 27.1 mm. of mercury per minute (approximately 1,000 feet per minute). Descent started immediately upon attainment of altitude. Interruptions of descent were frequent, especially in the 38,000-foot runs, due to the usual types of difficulties experienced by subjects on descent from altitude.

In order to simulate flying conditions as closely as possible, most of the chamber experiments were conducted in the pres-

ence of artificial airplane noise, using a Noise Generator* with a 55 watt Thordarson Amplifier (tone controls "normal") and a Jensen Concert Speaker (A12PM). Measurements of the noise with a calibrated system showed overall sound pressure levels, varying with the positions of the subjects in the chamber, between 101 db. and 109.5 db.; the average for all being 107 db.

Several representative types of plugs were selected for study:

1. A wax impregnated cotton imperforate type (TypeA†). These were chosen from the several available because this particular device had been given a high rating for acoustic attenuation in various independent studies.

2. A molded neoprene imperforate type (Type B‡).

3. A molded rubber perforate type (Type CI§ and Type CII¶). These two protectors have similar exernal appearance but utilize different acoustic filling, air-leak, etc. They were tested both in the standard production form and in a special model having the outer ends shortened (by the manufacturer) to facilitate wear under earphones.

4. Dry cotton (in the form of dental roll) used both as protective device having considerable high tone attenuation, and as an assured pressure equalizing device — a control necessitated both by the uncertainty of an airtight fit with the imperforate plugs and by the variability of the air-leak in the perforated types tested.

Immediately following the tests, the subjects completed the questionnaires, including remarks as to comfort, pain, removal of the plugs, etc. The ears were then examined for evidence of middle or external ear pathology and graded according to the severity of the objective signs in conformity with the classification below. All grading was done by the same examiner to minimize variations in judgment.

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*This generator was designed and constructed by the Psycho-Acoustic Laboratory, Harvard University.
†Flent Anti-Noise Ear Stopples.
‡N.D.R.C. V-51R Ear Warden.
§Sepco Ear Protector.
¶S.M.R. Ear Stoppers.

RESULTS.

In the accompanying tables are found the results of observations on 660 ears in high altitude flights (24,000 feet and 38,000 feet); 208 ears in medium altitude flights (10,000 feet); and 112 ears at ground level. Data are presented showing *1.* the incidence of aero-otitis externa in two high altitude (see Table 1), one medium altitude (see Table 2), and

TABLE 1. INCIDENCE OF AERO-OTITIS EXTERNA RESULTING FROM THE USE OF EAR PLUGS AT GROUND LEVEL AND IN SIMULATED HIGH ALTITUDE FLIGHTS (24,0000 AND 38,000 FEET) IN THE ALTITUDE CHAMBER.

		Aero-otitis Externa			
		Grade 1		Grades 2, 3 and 4	
Type Plug	Ears Tested	No. Ears	% Ears	No. Ears	% Ears
Imperforate (Type A)	103	16	15.5	6	5.8
Imperforate (Type B)	114	13	11.4	8	7 0
Perforate (Types CI and CII)	297	35	11.8	15	5.1
Cotton	80	3	3.7	0	0.0
Unplugged	66	1	1.5	1	1.5
Overall totals for high altitude tests	660	68	10.3	30	4.5
Combined totals and average per cent for commercial types (Types A, B, CI and CII)	514	64	12.9	29	6.0
Ear plugs tested at ground level (Types A, B, CI, CII and cotton)	112	0	0.0	0	0.0

TABLE 2. INCIDENCE OF AERO-OTITIS EXTERNA RESULTING FROM THE USE OF EAR PLUGS IN SIMULATED MEDIUM ALTITUDE FLIGHTS (10,000 FEET) IN THE ALTITUDE CHAMBER.

		Aero-otitis Externa			
		Grade 1		Grades 2, 3 and 4	
Type Plug	Ears Tested	No. Ears	% Ears	No. Ears	% Ears
Imperforate (Type A)	54	6	11.1	1	1.8
Imperforate (Type B)	50	8	16.0	3	6.0
Perforate (Type CI)	56	3	5.3	4	7.1
Cotton	40	1*	2.5	0	0 0
Unplugged	8	0	0.0	0	0.0
Overall totals for medium altitude tests	208	18	8.6	8†	3.8
Combined totals and average per cent for commercial types (Types A, B and CI)	160	17	10.6	8	5.0

*This ear associated with Grade 3 aero-otitis media.
†All ears in this group showed Grade 2 involvement.

one ground level group (see Table 1), as related to ear plug type; and *2.* miscellaneous contributory observations concerning factors of comfort and pressure equalization in the wearing of ear plugs at altitude (see Table 3).

TABLE 3. COMPARATIVE LEAK TESTS ON EAR PLUGS.

Type Plug	No. Plugs	% No Leak	% Slow Leak	% Good Leak
Type CI, standard, new	180	13	15	72
Type CI, standard, used	30	37	33	30
Type CII, (factory shortened), used	32	25	22	33
Totals and average per cent	242	17	18	65

Aero-otitis externa occurred in various degrees of severity, and for purposes of classification these were arbitrarily graded as follows (see Fig. 1):

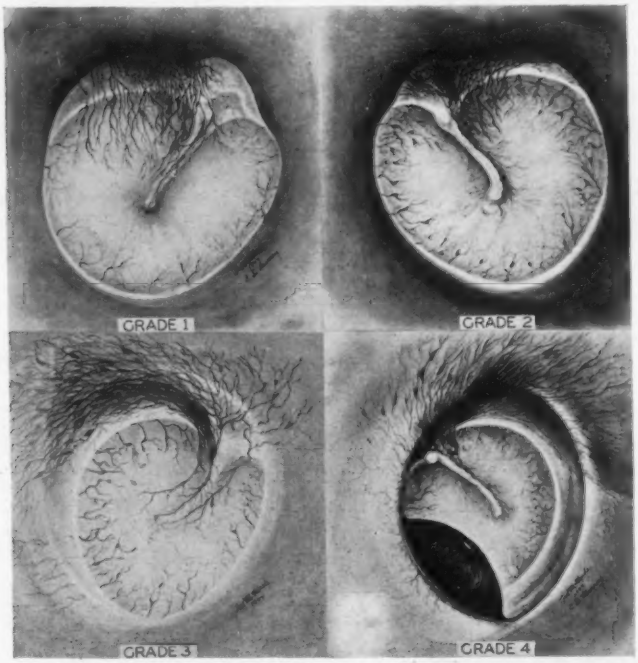

Fig. 1. Semidiagrammatic drawings showing various grades of vascular damage due to the use of non-perforated or inadequately perforated ear plugs during flight in aircraft.

Grade 1: Mild hyperemia and congestion of the superior and posterior-superior canal walls of the inner one-third of the external auditory canal. The tympanic membrane shows redness of the superior part of the drum and injection of the vessels along the handle of the malleus.

Grade 2: Marked redness and petechial hemorrhages involving the posterior and superior canal walls with a variable number of small irregularly shaped petechiae around the periphery of the tympanic membrane.

Grade 3: Severe redness, variable petechiae and small ecchymoses on the posterior and superior canal walls. Petechiae and ecchymoses may or may not be found on the tympanic membrane.

Grade 4: Hemorrhagic bullae involving the canal and tympanic membrane. These bullae, like those occurring in other conditions,[6,7] are bluish-black in color, are roughly hemispherical in shape and vary in diameter from a few millimeters to a size that almost completely blocks the ear canal. The region of most frequent involvement is the junction of the inner and outer halves of the canal (see Fig. 2), but blebs are occasion-

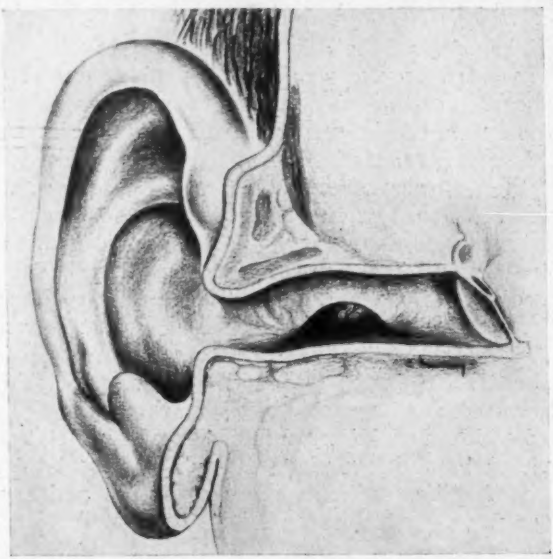

Fig. 2. Diagrammatic section of external auditory canal showing most frequent site of hemorrhagic bullae.

ally multiple and occur anywhere on the inner portion of the canal or on the tympanic membrane itself. At no time were any of these findings observed at points of direct contact between ear plug and skin.

It will be noted that the tabulation of external otitis separates the cases with simple reactions (Grade 1), which are probably of little practical significance, from the more severe types (Grades 2, 3 and 4), which include, respectively, petechiae, ecchymoses and hemorrhagic bullae, all of which are reactions involving rupture of capillaries or larger vessels.

High Altitude Experiments: The incidence of aero-otitis externa is markedly influenced by the type of ear plug worn (see Table 1). The findings in unplugged ears and in those plugged with cotton are alike in showing negligible incidence, which is to be expected on the basis of their low resistance to airflow. On the other hand, the other types of plugs tested are alike in having relatively high incidence of aero-otitis externa, in both the mild (Grade 1) and severe forms (Grades 2, 3 and 4); and they are correspondingly alike in having high resistance to airflow.

It will be observed that the incidence of aero-otitis externa is nearly but not quite zero in the unplugged and cotton plugged ears. For this small apparent incidence a difficulty of diagnosis appears to be responsible. It was noted that with the more severe grades of aero-otitis media an associated redness of the posterior-superior wall of the external auditory canal was occasionally seen with a diagnosis of Grade 1 aero-otitis externa; and, conversely, when severe traumatic external otitis occurred in the presence of a moderately retracted drum, a diagnosis of Grade 1 aero-otitis media could readily be made. Thus, there is some diagnostic uncertainty in the Grade 1 category. Actually, two of the three cases of mild external otitis with cotton (see Table 1) were associated with aero-otitis media and probably belong in this class. That this is a negligible source of error is evidenced by the fact that the unplugged and cotton plugged ears show about the same incidence of otitis media as the rest of the series, while showing a far lower incidence of aero-otitis externa.

It must be emphasized that the subjects were advised to remove ear plugs immediately upon the occurrence of pain or discomfort during descent. This means that the incidence of aero-otitis externa given in the tabulation is almost certainly far lower than it would otherwise have been, and may be taken as a minimal figure. This procedure was necessitated by the practical consideration that the subjects were awaiting assignment for aircrew training and would be temporarily disabled by the more severe grades of aero-otitis externa.

For the same reason, after the occurrence of a number of Grade 4 external otitis reactions in flights to 38,000 feet, tests on imperforate types of plugs (Types A and B) were discontinued, so that the number of experiments for these types at this altitude is considerably less than for others in 24,000-foot and 38,000-foot flights.

Medium Altitude Experiments: In Table 2 are shown the results of flights of 10,000 feet (all done in quiet) with the same rate of descent (27.1 mm. of mercury per minute). In this group the overall incidence of aero-otitis externa was only slightly less than in the high altitude series; however, no cases showing ecchymoses or hemorrhagic bullae were seen, reactions being limited entirely to Grades 1 and 2.

Control Experiments: Controls of two sorts are included in the series. In the first place, a group of 112 ears wearing the several types of plugs at ground level shows zero incidence of otitis externa (see Table 1), demonstrating that the otitis is not due to the simple presence of plugs in the ear canal. Second, the negligible incidence of otitis externa with unplugged ears (and cotton) in all altitude runs shows that aero-otitis externa is not produced by the pressure changes acting directly in the ear. These two controls together warrant the conclusion that blockage of the external canal prevents pressure equalization in the artificial chamber internal to the plug.

Aero-otitis in Actual Flight: It is of interest that this phenomenon has been observed not only under the somewhat artificial conditions of the altitude chamber, but has also been

seen as a result of the use of ear plugs during low altitude airplane flight. One patient seen recently, after an actual flight at 5,000 feet, during which non-perforated ear plugs were worn, complained of severe pain during descent and showed a typical hemorrhagic bulla involving the entire posterior-inferior quadrant of the tympanic membrane.

DISCUSSION.

It is surprising at first glance to note that the so-called "pressure equalizing" types of plugs (Type CI and CII) have about the same incidence of aero-otitis externa as the "non-equalizing" types. This is not so unexpected, however, when several things are taken into account. First, it is not automatically true that an unperforated plug such as the Type B gives an airtight fit in any given ear; on the contrary, this is often difficult to achieve. Second, movements of the jaw and face quite often will disturb an initially well placed plug. Finally, the "leak" in perforated plugs has been found extremely variable and frequently non-functional. Table 3 shows the results of rough, comparative leak tests on a number of plugs. The tests were performed by the same individual, using as nearly as possible the same criteria of leak, and consisted of mouth suction on a tapered receptacle into which the tip of the plug was sealed, with care to avoid obstruction of perforations in the tip or stem of the ear plug.

From the foregoing data on "perforated" type plugs, together with the data on aero-otitis externa, it seems that the pressure-equalizing feature is by no means reliable. Indeed, it is apparent that the pressure-equalizing type of plug has two materially conflicting functions to perform. On the one hand, good attenuation of sound, particularly at the low frequencies, calls for a high resistance to airflow (as seen in imperforate types of plugs); and, on the other hand, good pressure equalization requires a low flow resistance (as exemplified by Cotton) which offers little or no attenuation of low frequencies. The particular types of compromise plugs tested (types CI and CII) do not seem to have a sufficient pressure-equalizing function for use in high altitude flights.

It is of special interest in connection with the question of pressure equalization to note that the wax impregnated protectors, which were found to be the most comfortable at ground level, are given the poorest rating in high altitude runs. This is presumably because the self-molding characteristic which permits a comfortable fit in all shapes and sizes of ears also makes it relatively easy to obtain air-tight seal, thus causing discomfort during descent from altitude.

TREATMENT OF AERO-OTITIS EXTERNA.

Treatment of the mild and moderate grades of aero-otitis externa, for the most part, consisted of advice against the use of "non-perforated" or molded ear plugs during flight. The more severe hemorrhagic bullae (Grade 4) occurring on the canal wall were incised with a sharp myringotomy knife and the blood clot gently wiped away. A cotton wick saturated with Zephiran Chloride (1:1,000) or a solution of merthiolate (1:1,000) was then inserted into the external auditory canal. Twenty-four hours later the canal was carefully cleansed with hydrogen peroxide (3.5 per cent) and alcohol (70 per cent), and dry cotton was placed in the concha. Complete healing required seven to 10 days. No secondary infections developed in any of the cases observed.

SUMMARY AND CONCLUSIONS.

a. Aero-otitis externa, a hitherto undescribed syndrome, is discussed. This syndrome of hyperemia, petechial or ecchymotic hemorrhages, or large hemorrhagic bullae involving the soft tissues of the external auditory canal and tympanic membrane occurred following the use of ear plugs in descent from altitude.

b. Both perforate and imperforate type ear plugs caused severe aero-otitis externa (Grades 3 and 4) during descents from 24,000 feet and 38,000 feet (decent rate of 27.1 mm. of mercury per minute).

c. No cases of severe aero-otitis externa (Grades 3 and 4) occurred with ear plugs tested in flights to 10,000 feet, with above descent rate. There was, however, an incidence of 5 per cent aero-otitis externa of Grade 2 severity.

d. In view of the high incidence of moderate and severe aero-otitis externa found in this series, imperforate or inadequately perforated ear plugs should not be used by flying personnel whose duties require rapid descent in aircraft.

ACKNOWLEDGMENT.

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WAR OTOLARYNGOLOGY.*

COL. NORTON CANFIELD, M.C., U.S.A.

War otolaryngology has many phases. It is the sum total of the specialty experience of medical officers who gave the service, and of the personnel who received it. When the war came, the Army Medical Corps was expanded at a tremendous rate, and there was then too little time to embark on a carefully planned and coordinated program to utilize to the best advantage the specialty service then available in our great country. The specialists in the Regular Army were promptly given administrative posts and the professional service rendered to patients was quickly assumed by the civilians who were called to duty.

I will discuss war otolaryngology under four headings:

1. The otolaryngologists' position in the American Army today.

2. Otolaryngology in non-combat troops.

3. Otolaryngology in combat troops.

4. Otolaryngology in rehabilitation projects.

To understand the position of the otolaryngologists in the Army it must be first realized that the Army, working under the President, the Secretary of War and the Army General Staff, is divided into three main Forces, the Ground Force, the Air Force and the Service Forces. The Medical Department is a division of the Service Forces, although many medical officers are in the Ground Force and in the Air Force. The Medical Department is charged with providing medical service to the entire Army. Within it there are several Corps, including the Medical Corps, Dental Corps, Sanitary Corps, Pharmacy Corps, Nursing Corps, Veterinary Corps and the Medical Administrative Corps. Under the Medical Corps

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come the professional officers who are graduates of accredited medical schools and in this group are included the otolaryngologists.

Representation at high administrative levels gives the individuals working a sense of security. In the Medical Corps it is extremely important to the morale of the specialists. In otolaryngology up to July, 1944, there was no representative for the specialty at the Surgeon General's office. At that time an officer was appointed chiefly to coordinate the Hearing Rehabilitation Program but was not given a rank commensurate with his responsibilities and was not given support for otolaryngology in matters of importance to the sick and wounded, or the specialists involved. For these reasons he could not truly represent the specialty, nor could he bring to the effective attention of the proper authorities the urgent needs of the Army for otolaryngologic care. This is the crux of the situation regarding the cooperation between civilian specialists and Army medical authorities. Because of the failure on both sides to understand the problem, the otolaryngologist in the Army finds himself in his present position; however, because of the large number of deafened soldiers, many of whom were taken into the Army with their defects, and the Army's plan for rehabilitation, the final appointment of a full-time consultant to the Surgeon General was effected.

Civilian consultants were appointed also, to be called when needed, and were effective, especially in the Aural Rehabilitation Program and the Air Force radium therapy projects. In other phases of otolaryngology their influence was meager.

In the European Theater of Operations the Chief Surgeon requested and obtained a truly representative Professional Consultants Division working directly in his office. This group consisted of 14 specialists in which otolaryngology was represented by a full-time officer. Many problems directly affecting the care of soldiers were referred to him for recommendation. The Chief of the Surgical Consultants Division, Gen. Elliot Cutler, was made cognizant of specialty problems and in many instances carried these problems to the proper authority for their settlement. The otolaryngologic consultant was personally acquainted with and knew the qualifica-

tions of most of these specialists in the Theater and he was able to make effective recommendations for the assignment of many of these officers. Approximately 95 per cent of some 300 officers who had specialty training in otolaryngology were assigned to duty requiring their specialty ability. In many instances, however, the ability was not completely utilized, because of the nature of warfare and activities of their particular hospital during different phases of the campaign.

The individual otolaryngologists did their work chiefly in the organized hospitals. Most of the hospitals in which they were located were under the direction of the Service Force, but some were actually in hospitals attached to the fighting Army, under Ground Force control.

Within each hospital, the organization required that the professional service be divided into two sections, medical and surgical. Under the surgical service, the otolaryngologists and ophthalmologists were considered to represent an individual section. In approximately 3 per cent of the general hospitals, the otolaryngologists and ophthalmologists operated a service which was separate from surgery, but in all other hospitals they were administratively and professionally under the Surgical Service.

Until August, 1944, the Administration of general hospitals permitted either the ophthalmologists or the otolaryngologists to attain the rank of Major in overseas hospitals. At this time the organization was changed, so that only with the greatest difficulty could the otolaryngologist be made a Major, while the ophthalmologist was given the preferential rank. This led to considerable anxiety and actually did interfere with the care of patients, because otolaryngologists who had already attained the rank of Major were very difficult to move from one hospital to another. Considering that in these same hospitals the radiologists, the psychiatrists, the chief nurse and the chief dental officer could attain the rank of Lieutenant Colonel, the reason for the otolaryngologists' Army rank was not obvious.

OTOLARYNGOLOGY IN NON-COMBAT TROOPS.

In every medical installation in the Army which pretends to care for sick patients, the demand for otolaryngologic care

is always present. Most medical installations included this specialist, or an officer who could do both ophthalmology and otolaryngology. This made it necessary to provide this type of care in all such installations, or to have it available from a neighboring unit, where such a specialist was on duty. At no time in the European Theater did the total number of otolaryngologists, including the combination men, reach more than 70 per cent of the Army requirements, according to the directed plan for the various units. To fill these vacancies it was often necessary to assign an officer to care for these patients and direct him to call for consultation from another unit when difficult cases were encountered.

For non-combat Army personnel, the otolaryngologic care is not geatly different from the care necessary to the ordinary healthy civilian group. Approximately 80 per cent is of a routine uncomplicated nature. Fortunately, the Army had provided very excellent preventive medical measures, so that in the European Theater there was never any extensive epidemic of infectious diseases. The usual run of infected sinuses, ears and mastoids was encountered. Several reports of significant groups of severe complications have been already published. A small number of unusual neoplasms, including a case of Hodgkin's disease of the vocal cords and several carcinomas of the larynx were returned to the United States for definitive care. In these troops the Army demands that they return to duty or be treated as ambulatory patients, so that they will lose as little time as possible from their routine Army duties.

At various places throughout the hospital population in England there were located some of our most outstanding otolaryngologists. These officers always found that their out-patient clinic was extremely popular, and it soon become known by the surrounding troop medical officers that certain specialists were available in certain hospitals. This made their load particularly heavy, the most striking example of which was operated by Maj. Gordon Hoople at the 52nd General Hospital in Western England. In a two-year period he had an average of more than 1,800 patients per month go through his out-patient department, during which time he

had a single office assistant at any one time. He was able to work out a program whereby patients with Vincent's infection of the tonsils were given a type of care which required only a two-day hospitalization. The treatment consisted chiefly in a very thorough cleansing process for the ulcers and the use of sodium perborate deep in the cavity. This work has been reported in the *Journal of the American Medical Association.*

Results with the use of chemotherapy varied in the hands of different men, some reporting extremely good results for the prevention of complications from upper respiratory infections and others reporting it less effective. From the total experience, it is very obvious that the use of sulfa drugs and penicillin requires very diligent attention to the patient during the time he is having the drug, and for about 10 days after the drug has been discontinued. This is necessary because of the lurking virulence of the organism causing the infection, which may suddenly increase when the drug is discontinued. In many cases, this led to severe complications. In nearly all cases of sinus thrombosis and otitic brain abscess, the patient had had a preliminary course of one of the sulfa drugs. Particularly was this important when movement of patients from one hospital to another was necessary to keep pace with the moving Army.

Reports from the Pacific area mention another disease in non-combat troops which assumed a major rôle. This was the group of mycotic infections of the external ear. They were particularly annoying and extremely difficult in the tropics and accounted for many of the casualties in that region. I have no specific information as to the total numbers, but when the final records are assembled this will assume major importance in the otolaryngologic diseases of combat and non-combat troops.

OTOLARYNGOLOGY IN COMBAT TROOPS.

When the Army is on the march and during combat, the otolaryngologist still is required to take care of all the various diseases of his particular region. When the battle starts, the plastic and traumatic surgeons at once come to the fore and the otolaryngologist is usually relegated to an ancillary posi-

tion for the care of the wounded. In units where the surgical chief and the plastic surgeon were cognizant of the complications which could arise, if the paranasal sinuses and the mastoids are involved, the otolaryngologist assumed his rightful position. In those instances in which the otolaryngologist was not consulted, the deep tissues of the face and mastoids were sometimes untouched. This frequently resulted in a satisfactory external closure of the wound, but destructive processes beneath the surface would cause future complications. Many of the very worst plastic cases which are now being treated had injury to the deep tissues which was not appreciated at the time of wounding.

As the campaign progressed in the European Theater, this was finally realized and directives were distributed to overcame this defect in previous cases. It was directed that any patient whose wound was caused by a missile that could have penetrated into one of the sinuses or the mastoid, and whose X-ray showed increased density in that region, should have complete exploration before the external wound was sutured. During this war many foreign bodies were found which were not visible by the X-ray. Such things as clothing, portions of the helmet lining, pieces of plastic material and wood were often found inside the sinuses if they were carefully inspected. If this debris was not removed, subsequent infection would usually be very serious. During the preliminary stages of treatment of these cases, the chemotherapeutic agent did hold many of the infections in check, but later, if foreign bodies and necrotic tissue had not been removed, subsequent infections would frequently be extensive and would reopen the external wounds before final healing took place.

Some of these cases will be encountered in civil practice and if there is infection within sinuses in a patient who has been wounded in this region and there is not good evidence that his sinus has been carefuly debrided, immediate attention to this detail will save many days in his final recuperation.

Little need be said of the importance of the Air Force in this war. Aviation medicine has progressed at a rapid pace and in regard to the ears and sinuses the otolaryngologist has

contributed to this advance. During the European campaign, the Air Force, before D-Day based largely in England, was much of the time in the comparatively safe regions of the eastern part of that country; however, within a few short hours many hundreds of bombers would be under fire of the enemy, and many men were wounded. Secondary missiles were very frequent, and many parts of the planes were driven into different regions of the body. The changes in pressure accompanied by intense cold were other factors demanding the most diligent attention.

Early in the bombing campaign it was realized that the problems of aero-otitis media and aero-sinusitis were far from solved. Based on his previous experience with radium treatment of the nasopharynx, Maj. E. P. Fowler, Jr., was authorized to use this treatment on flying personnel. By means of a very careful experimental approach, he was able to return men to flying duty who otherwise would have been returned to the states. The difficulties involved were many, but results were so encouraging that the Air Surgeon sent three other officers, trained in the United States under Dr. Crowe, of Johns Hopkins, to the European Theater to expand the program. Reports have already been published by Maj. Fowler and the final report from the Air Force from all theaters of operation will give us the final picture. It will probably be regarded as a very significant addition to our therapeutic methods and will be an established means of treatment for appropriate cases. To study the problem further, Maj. Fowler was largely responsible for the acquisition by the Army Institute of Pathology of 150 pairs of temporal bones, most from aviators who gave their lives in combat. These specimens are now being prepared for microscopic study and will be the basis for an important scientific contribution to otology.

The fourth phase of war otolaryngology concerns the rehabilitation of the casualties. Five main groups are now the concern of the otolaryngologists.

The first of these is the deaf. For years the ideal medical treatment for this large group of citizens has been only the dream of the medical profession. So involved are the patho-

logic and psychologic phases concerned that no inclusive program, where all the specialists involved worked under unified direction, has previously been in operation. Early in 1944, the numbers of deafened soldiers became so large that the rehabilitation branch of the Surgeon General's office recommended special centers for the deaf. The program was started at Walter Reed General Hospital and later moved to Deshon General Hospital at Butler, Pa. Another started at Borden General Hospital at Chickasha, Okla., and the third at Hoff General Hospital, Santa Barbara, Calif. After some weeks of operation, the director at Borden, Maj. Leslie Morrissett, was ordered to the Surgeon General's office as consultant to coordinate the three centers. The succeeding developments attest to his foresight and judgment and to date approximately 10,000 soldiers have had the benefit of the extensive rehabilitation program. At each center under the direction of the Chief of Otolaryngology, a group of 40-60 specialists handle a patient load of 300 to 600 for a period of about eight weeks. These specialists include the otologists, the acoustic physicists, the clinical psychologists and psychiatrists, the speech correctionists, the lip-reading teachers, technicians to fit hearing aids with plastic ear molds, and occupation counselors.

These centers (two of which are still operating) point the way for future rehabilitation programs and have attacked the problem of deafness from the standpoint of the completely integrated human being. There have been failures, but, as preliminary programs born and nurtured in a country at war, they will stand as significant beacons to point the way for the future.

A wound not mentioned under combat otolaryngology is that which eliminates the function of the facial nerve. Direct and indirect trauma interrupt the nerve impulses and result in the disfigurement with which you are all familiar.

Controversy has existed concerning the best methods of treatment, but there is no satisfactory substitute for return of function which results from the joining of the central and peripheral ends of the injured nerve. This can be done by

suture or nerve graft as advocated long ago by Ballance and Duel. The contribution by otolaryngologists in this war is that, regardless of the appearance of the wound, there is a chance that the nerve can be joined. To the everlasting credit of three otolaryngologists, it now seems that this type of therapy, long looked upon by other specialists as of doubtful value, will be finally established. These men are Frank D. Lathrop, Gordon Hoople and Albert C. Johnson, who, during the European campaign operated upon 40, 12 and eight cases respectively, suturing some and grafting others. So satisfactory have been the results that Col. Lathrop has been made director of the Army Facial Nerve Project at Cushing General Hospital, where another 60 cases now in Army hospitals will be treated by similar methods during the next six months.

The injured larynx presents difficulties of rehabilitation. While a named center for these cases has not been established in the Army, Maj. Mercer Lynch at Walter Reed Hospital has handled many of these cases. His work will be the basis for a forthcoming paper on the subject, and new techniques are being established by him. The restoration of the voice by various means is the important consideration after the airway has been established. Again, the psychological phase requires even more attention if these men are to be restored to a useful and satisfying life.

The last two groups I shall mention are the chronic suppurating ears and sinusitis. We have struggled with these for years, and new means of treatment during the war have not been revolutionary. Chemotherapy has been used but has been disappointing. Attempts to study these cases in the Army have not been very fruitful. We will continue to see these cases for many years to come. They deserve our profound attention, and re-evaluation of these two groups of patients should be our constant concern.

The fighting war is over, but the casualties remain. The Medical Corps' job is still not finished. The medical profession's duty is to take over this group of our returning citizens and make the benefits of scientific medicine available to them all.

CONGENITAL PREAURICULAR SINUSES.

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Congenital preauricular sinuses which cause symptoms sufficiently annoying to justify operation are comparatively rare. Pastore and Erich[1] found 13 patients had received surgical therapy for this condition in a period of 20 years at the Mayo Clinic. For comparison it is worthy of note that in a 30-year period, at the same institution, Neal and Pemberton[2] found that 319 patients had had surgical removal of lateral cervical cysts and fistulas. Penick[3] stated that seven patients with infected preauricular cysts or sinuses had been treated by him, but the period of time over which they extended was not mentioned. Dingman[4] reported a case that was treated by surgical excision at the George F. Geisinger Memorial Hospital in 1939, and Harding,[5] in 1942, reported a similar case treated at the same institution.

In 1939, Havens[6] suggested the use of electrocoagulation in the treatment of certain of these sinuses which have been the seat of repeated infection.

In the past four years, I have examined four patients with this condition who needed operation. The method suggested by Havens was used on two of these cases (Cases 1 and 2). One case on which this method would have been suitable did not receive treatment (Case 3). One case had bilateral sinuses which drained profusely, but since there had been no abscess formation it was felt that surgical excision was the method of choice. This patient also had marked deformity of both external ears, which fact supports the belief that congenital preauricular sinuses result from incomplete fusion of the three nodules from which the tragus and helix are devel-

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oped. These nodules are derived from the first branchial arch (Case 4).

Case 1: A 10-year-old colored girl was admitted to the Henry Ford Hospital on Jan. 25, 1942. There was a history of the formation of an abscess over the left preauricular region five years previously. This had ruptured spontaneously in a few days. The drainage had stopped after an indeterminate period of time, but there had been several recurrences of the same process, and on one occasion surgical incision and drainage had been carried out (see Fig. 1).

Fig. 1. Preauricular sinus and sinus secondary to abscess formation.

On Jan. 26, 1942, under avertin and novocaine infiltration anesthesia, methylene blue was injected into the sinus tract. The main tract was then exposed by incision, and after this and some of the larger ramifications were dissected out, the entire area including all of the epithelial lined ramifications was thoroughly electrocoagulated. A bismuth gauze pack was then inserted and the skin edges closed loosely. In about four weeks the wound had healed completely (see Fig. 2).

Case 2: A 10-year-old white girl was admitted on May 25, 1943. There had been drainage from a right preauricular sinus since birth. One year previously, an abscess had formed in the right preauricular region. This had been drained surgically. There had been several recurrences followed by spontaneous drainage (see Fig. 3).

Fig. 2. Completely healed.

Fig. 3. Preauricular sinus following abscess formation.

Under avertin and nitrous oxide anesthesia the sinus was opened with the electric scalpel, and the epithelial lining of the main sinus and all of its ramificaitons thoroughly electrocoagulated. A bismuth gauze pack was inserted and the skin was closed loosely with silk sutures. One month later, the wound had almost completely healed.

This patient has not been observed further. Efforts to contact her directly have been unsuccessful; however, a communication from her local physician in another city informs me that following an injury to her face in June, 1944, an abscess formed in the preauricular region. It seems recurrence due to incomplete removal of the tracts must be strongly suspected until evidence to the contrary is available.

Case 3: A 13-year-old colored girl was examined March 16, 1943. There was present a left preauricular sinus which had become abscessed and had drained recurrently for several years (see Fig. 4). Operation was advised but refused.

Fig. 4. Preauricular sinus and sinus secondary to abscess formation.

Case 4: A white boy, age 8 years, was admitted on Feb. 6, 1942. There was a history of recurring drainage from bilateral preauricular sinuses for several years. There was congenital deformity of both external ears.

Under ether and nitrous oxide anesthesia after injecting methylene blue into the sinuses, the left one was dissected out. It extended rather deeply in the region of the external auditory canal. The wound was closed with silk and a small, soft rubber drainage tube inserted. A similar procedure was carried out on the left side. The sinus was not quite so extensive on this side.

Three weeks later the wounds had completely healed.

The patient was not seen for two and one-half years. At that time there had been no recurrences of drainage, but a keloid 1.5 cm. in diameter had formed in the scar on the right side, and a smaller one (0.5 cm.) on the left side. These were removed surgically on July 31, 1944. Several weeks later, Roentgen therapy was given, but control of the keloid recurrence has not been complete (see Fig. 5).

Fig. 5. Keloid formation following excision of bilateral preauricular sinuses. Deformity of both external ears.

The tendency to keloid formation in this patient makes one hesitate to proceed with the correction of the deformed ears.

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Henry Ford Hospital.

BRITISH NATIONAL HEALTH SERVICE BILL.

Any fair-minded Britisher must come to the conclusion that the medical service promised under the overdue National Health Service Bill will fail because it is dependent upon the following anti-British methods, namely:

1. It is unintelligent to guarantee 45,000,000 people "adequate" medical and specialist attention, drugs, appliances and hospital treatment, and, at the same time, make civil servants of the doctors who support the Health Service Scheme so that they will work more or less to fixed hours without being dependent on their patients for their remuneration;

2. It is short-sighted to guarantee 45,000,000 people "adequate" medical treatment unless, by negotiation, the cooperation of specialists and doctors with long experience has first been obtained; because even if all the remaining doctors supported the Health Service Scheme they must have specialist and experienced medical knowledge behind them;

3. It is injudicious to offer free dentistry, dentures, etc., even with qualification, because the government should know that there are insufficient dentists to meet present needs; further, the tie between a dentist and a patient is a fleeting one, so that if all the dentists supported the Health Service Scheme and became salaried civil servants, working to fixed hours, the number of patients who do get treatment today would be much reduced;

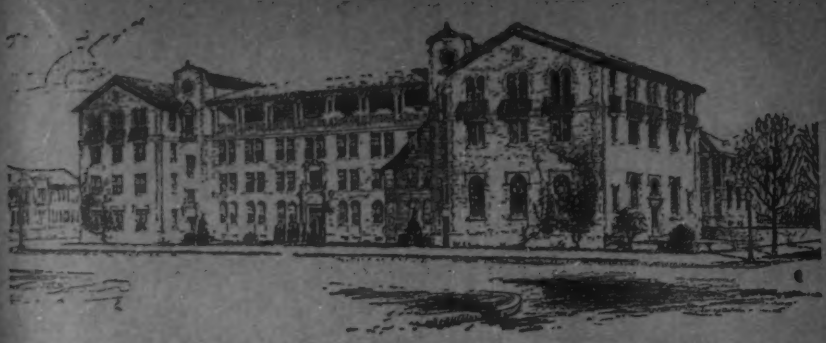
4. It is unwise to recommend pooling the remuneration of doctors supporting the Health Service Scheme, because the doctor who looks upon his profession mainly as a source of income benefits at the expense of the doctor who loves his work and is interested in his patients;

5. It is dictatorial, in this so-called "land of the free," to threaten, without negotiation, thousands of its most honorable citizens with the loss of their income from panel patients unless they do support the Health Service Scheme;

6. It is illegal to prevent hospitals from reaping the benefits of trust funds specifically bequeathed to them;

7. It is incredible that members of the medical profession, in contrast with millions of other citizens of Great Britain (individuals, partnerships, shareholders in limited liability companies and shopkeepers), should not be permitted to sell their goodwill, created by years of hard work and service to the community, on the pretext that if they have linked themselves up with the Health Service Scheme before the "appointed day" they will be paid compensation when they retire; doctors who join after the "appointed day" are even more unfairly treated because they not only cannot sell their goodwill but get no compensation.

The foregoing very interesting statement concerning the British Health Service Bill has been received from Frederick Thoresby, 161 Upper Tulse Hill, London, S. W. 2. Many of his remarks are appropriate to the situation in this country, and we thought that our readers might like to see them.—[Editor.]



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